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Late Quaternary paleoceanography in Kane Basin, Canada and Greenland.

Kris Allen. Marentette
University of Windsor

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LATE QUATERNARY PALEOCEANOGRAPHY IN KANE BASIN, CANADA AND GREENLAND

by

Kris Allen Marentette

A Thesis
submitted to the
Faculty of Graduate Studies and Research
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ABSTRACT

Benthonic foraminiferal assemblages from two cored sections in Kane Basin are characterized by _Buccella frigida_ (Cushman), _Cassidulina reniforme_ Nørvang, _Cassidulina teretis_ Tappan, _Cibicides lobatulus_*(Walker and Jacob), _Elphidium excavatum_ (Terquem) forma _clavata_ Cushman, _Islandiella helenae_ Feyling-Hanssen and Buzas, _Islandiella norcrossi_ (Cushman) and _Nonionellina labradorica_ (Dawson). The benthonic foraminiferal assemblages at Site 31 in western Kane Basin indicate that bottom-water temperatures were between -1 and 2°C and salinities ranged from 28 to 33‰ during the Late Quaternary. Six zones are recognized in the cored section from Site 32 in eastern Kane Basin. Foraminifers are absent in the stratigraphically oldest and youngest zones, Nos. 1 and 6, respectively. Bottom-water temperatures increased from Zone 2 (-1 to 2°C) in the lower part to Zone 5 (0 to 4°C) in the upper part of the section. Similarly, bottom-water salinities increased from Zone 2 (28 to 33‰) to Zone 5 ($>$34‰).

Temperatures between 0 and 4°C are inferred for the surface waters during the Late Quaternary at both sites on the basis of monospecific planktonic foraminiferal assemblages characterized by sinistrally coiled _Neogloboquadrina pachyderma_ (Ehrenberg).

Gypsum crystals are present in the upper part of the section (Zones 5 and 6) from Site 32. Oxidation of sulphides in the sediment released dissolved sulphate and lowered the

pH of the interstitial water which dissolved the calcareous foraminiferal tests. Desiccation of the sediment resulted in increased concentrations of calcium and sulphate and precipitation of gypsum.

Radiocarbon dates on benthonic foraminifers from the lower parts of the cored sections indicate that marine sedimentation began <u>circa</u> 9200 and 7600 radiocarbon years BP at Sites 31 and 32, respectively.

To Martha, my parents and Mandy.

ACKNOWLEDGEMENTS

I am grateful to Dr. C. G. Rodrigues for his informative discussions and advice throughout the project. I thank Dr. W. Blake, Jr., of the Geological Survey of Canada for providing the cored sections and the radiocarbon age determinations on invertebrate fossils from the sections. The receipt of the Natural Sciences and Engineering Research Council Postgraduate Scholarship (PGS 1 and PGS 2) for this project is gratefully acknowledged.

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INTRODUCTION

Foraminifers have been used to interpret Quaternary paleoceanography in Frobisher Bay and Baffin Bay (Fig. 1). Osterman (1984) related benthonic foraminiferal assemblages from a cored section to the advance and retreat of the ice margin in Frobisher Bay during the Late Quaternary. Mudie and Aksu (1984) compared oxygen-18, foraminiferal, dinoflagellate and pollen records in a cored section from Baffin Bay. They concluded that ice-free water in Baffin Bay and Labrador Sea played an important role in supplying moisture to the Laurentide and Greenland Ice Sheets during the last 300 000 years.

There is only one published report on the Late Quaternary foraminiferal fauna in Kane Basin which is situated between Ellesmere Island and Greenland in the Canadian Arctic Archipelago (Fig. 1). Phleger (1952) described the benthonic and planktonic foraminifers in a bottom sediment sample from southern Kane Basin. The purpose of this study is to describe the foraminiferal fauna in two cored sections from Kane Basin and to use the foraminiferal fauna to interpret the Late Quaternary paleoceanography of the area.

STUDY AREA

Physiography

The submarine topography of Kane Basin is characterized

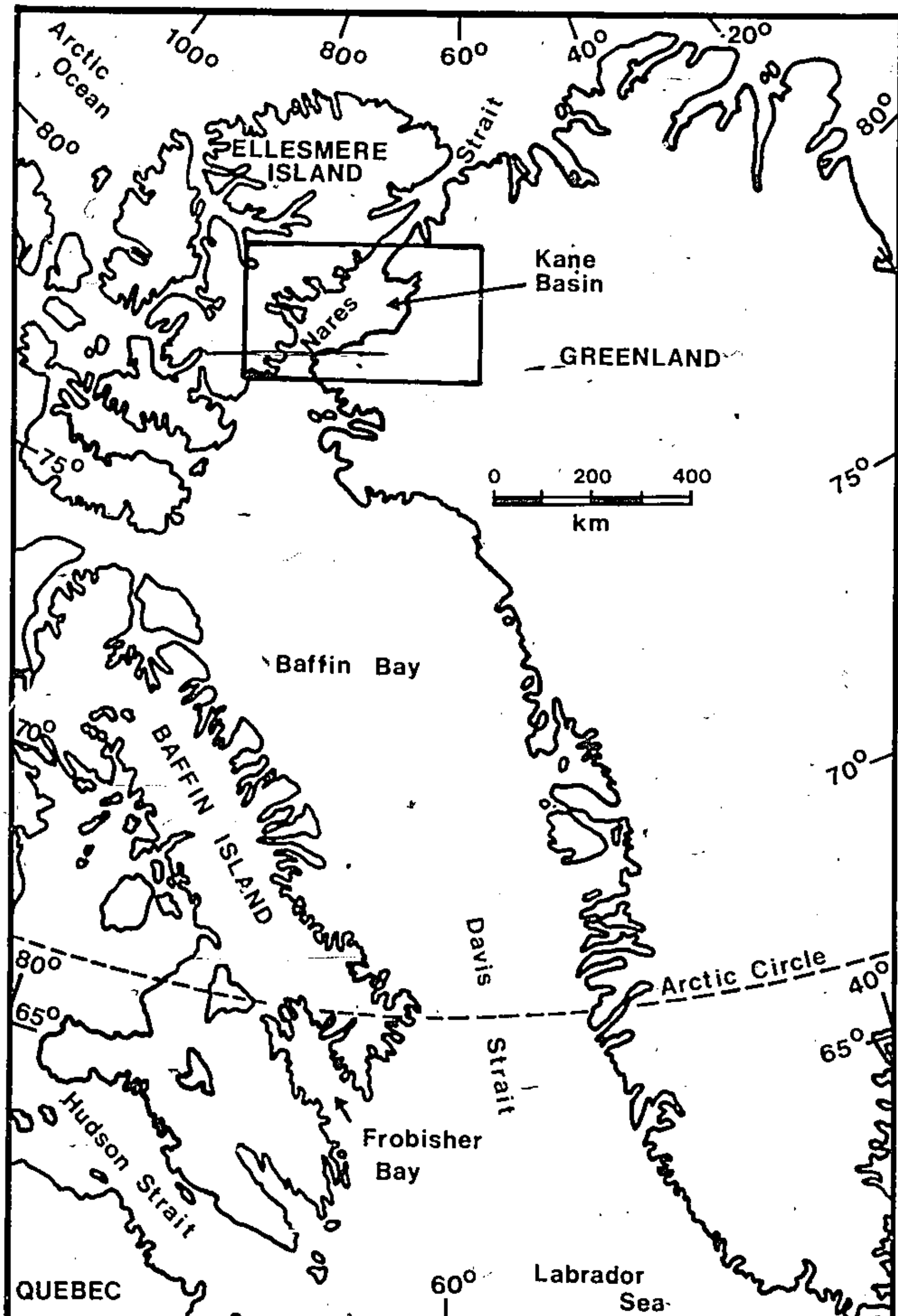

Figure 1: Location map of part of the Canadian Arctic Archipelago. The outlined area is shown in greater detail in Figure 2.

by two shallow troughs separated by a gently sloping northeast-southwest trending ridge which is shallower near Washington Land and deeper towards Smith Sound (Fig. 2). Maximum water depth in the trough adjacent to Greenland is greater than 400 m. The trough on the west side of the ridge is parallel to the Ellesmere Island coast and ranges from 200 to 300 m in depth. Water depths are greater than 400 m south of Bache Peninsula. Dunbar et al. (1967) reported that the limiting sill depth in Nares Strait (Fig. 1) is 250 m.

Oceanography

Kravitz et al. (1987) reported that Arctic pack ice, icebergs and sea ice are present in Kane Basin. Arctic pack ice is dense, relatively old ice which originates in the Arctic Ocean to the north and slowly drifts south through the basin and into Baffin Bay over a period of years. Icebergs are formed by the calving of ice at the terminus of glaciers. Sea ice forms between October and March and breaks up in July or August. Dunbar (1979) pointed out that the eastern part of Kane Basin, where wind conditions are less severe, appears to be out of the main line of current and ice movement. Therefore, during the fall and spring the eastern part of the basin is more icebound than the western part which is on a direct line between Kennedy Channel and Smith Sound. However, during the summer months there tends to be less ice in the eastern part of the basin and an increase in the amount of ice along the coast of Ellesmere Island. The increase in the amount of ice adjacent to the

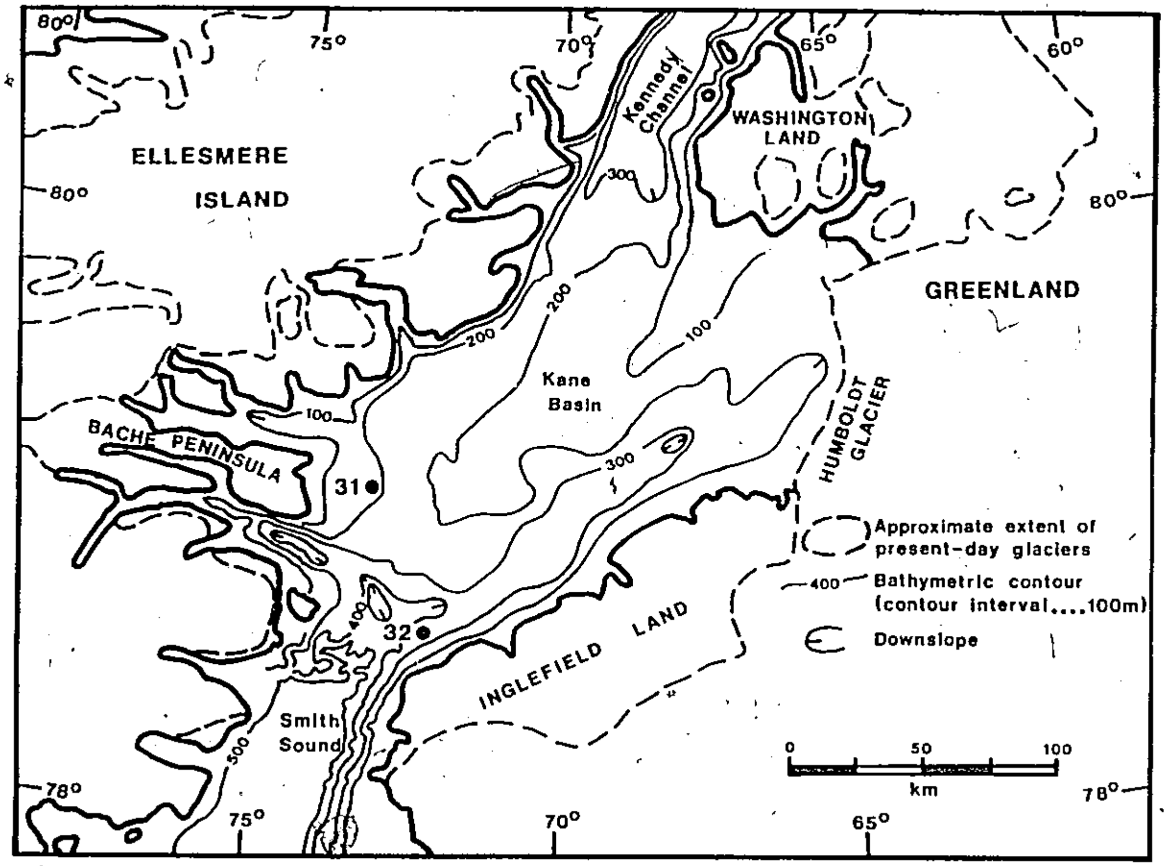

Figure 2: The bathymetry of Kane Basin and location of cored sections.

Ellesmere Island coast can be attributed, in part, to katabatic winds flowing from the Greenland ice cap across the Humboldt Glacier and a net southward movement of ice through Kennedy Channel and Kane Basin into Baffin Bay (Arctic Pilot, 1976).

The temperature and salinity conditions in Kane Basin discussed below are based on the data reported by Franceschetti (1964) and obtained during the summer 1963 cruise of the USCGC Evergreen. Temperature readings from depths shallower than 10 m are generally greater than 0°C. Salinities over the same depth range are generally less than 32.0‰. In the northern part of the basin the temperatures are below 0°C between 10 and 200 m and greater than 0°C below 200 m. Temperatures are less than 0°C at depths greater than 10 m in southern Kane Basin. The 34.0‰ isohaline is present at a depth of 100 m in the northern part and 200 m in the southern part of Kane Basin. In the central part of the basin the 34.0‰ isohaline varies from 125 m along the coast of Ellesmere Island to approximately 200 m off the coast of Greenland.

Moynihan (1972) demonstrated that the major flow of water between the Arctic Ocean and Baffin Bay occurs along the western side of Kane Basin. Muench (1971) and Sadler (1976) reported that occasional influxes of northeasterly flowing water enters Smith Sound and possibly Kane Basin at depths shallower than 250 m. The exact cause of the incursions is unknown. Dunbar *et al*. (1967) concluded that the water at depths greater than 200 m enters Kane Basin from the Arctic Ocean.

Sediments

Uchupi (1964) described eight grab samples from Kane Basin. He reported that the samples are gray to reddish-brown, poorly sorted, calcareous, sandy silts containing appreciable quantities of gravel. Uchupi (op.cit.) concluded that the grab samples consist mainly of ice-rafted materials.

Kravitz (1982) examined the texture and mineralogy of the surficial and sub-bottom sediments in Kane Basin and classified them as Holocene and Relict. The Holocene sediments were divided into sediments dominated by ice-rafting or by water transport and Relict sediments were divided into the Ellesmere Island Till (Till 1) and Greenland Till (Till 2). Characteristics of the sediments are listed in Table 1 and their distribution in the basin is shown in Figure 3. Ice-rafted sediments are present near the Humboldt Glacier and in the south-central part of the basin northwest of Inglefield Land. Water-transported sediments are found off Inglefield Land. The Ellesmere Island Till (Till 1) is present off Ellesmere Island. The Greenland Till (Till 2) is exposed along the ridge that extends south of Washington Land and is overlain by water-transported sediments off the coast of Inglefield Land. Kravitz (1982) concluded that the Ellesmere Island Till (Till 1) and Greenland Till (Till 2) were

Table 1: Characteristics of the sediments in Kane Basin (from Kravitz, 1982).

Sediments	Ellesmere Island Till (Till 1)	Greenland Till (Till 2)	Ice-rafted Sediments	Water-Transported Sediments
Sedimentary structures	None	None	Coarse bedding, Laminae, Cross-laminae	Coarse bedding, Laminae, Cross-laminae
Pebble orientation	No	No	Yes	Yes
Bioturbation	None	None	Weak	Strong
Shell material	None	None	Yes	Yes
Diatoms	Surface only	Surface only	Surface and occasionally downcore	Surface and commonly downcore
% Gravel	15	22	7	1
% Sand	33	41	20	4
% Silt	29	23	31	44
% Clay	23	14	42	52
Mean grain size	Very fine sand	Fine sand	Medium silt	Very fine silt
Sorting	Extremely poorly sorted	Extremely poorly sorted	Very poorly sorted	Very poorly sorted

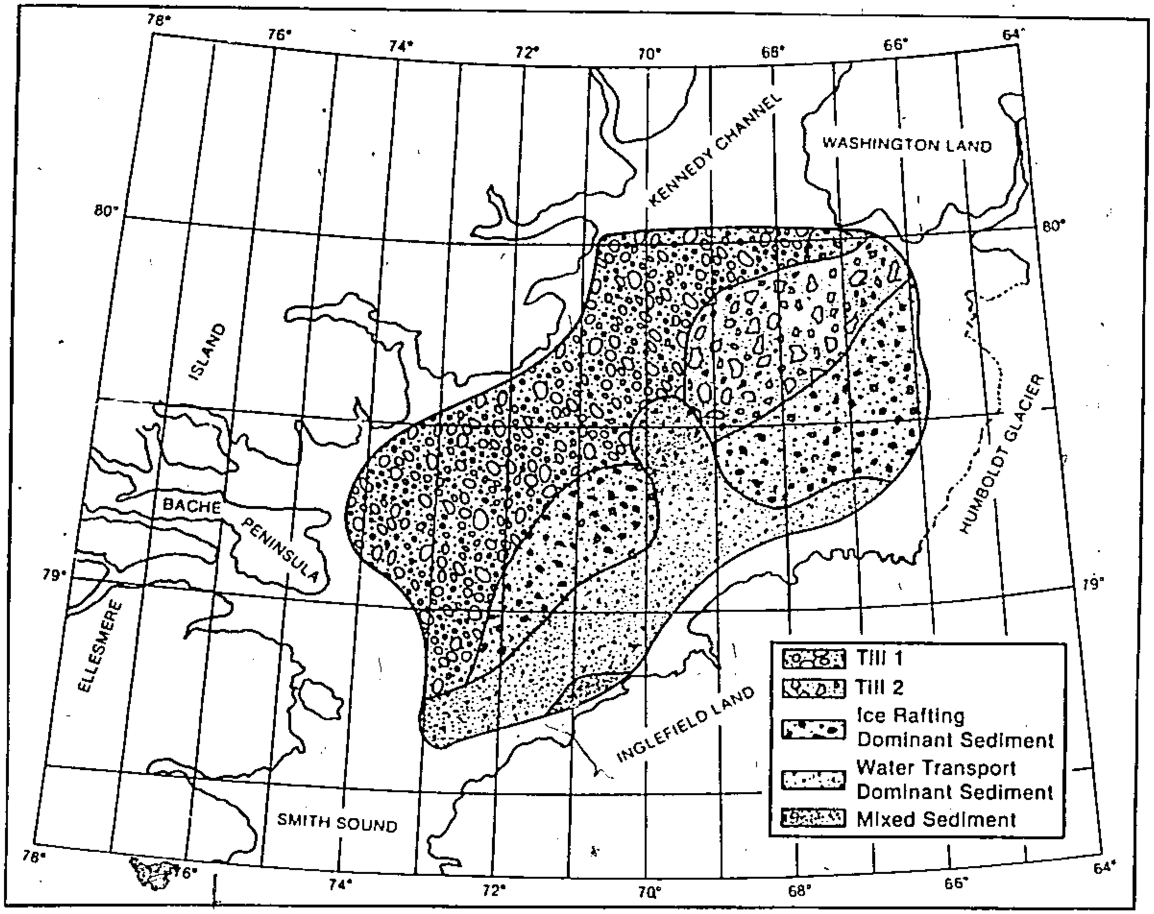

Figure 3: Distribution of surficial sediments in Kane Basin (from Kravitz, 1982). Till 1 = Ellesmere Island Till and Till 2 = Greenland Till.

deposited contemporaneously by subaerial melting of continental glaciers. However, he pointed out that sediments similar to till can be produced by intensive ice-rafting in an environment where there is very little or no reworking of the sediments.

MATERIALS

The two cored sections used in this study were collected during the 1974 eastern Arctic cruise of the CSS Hudson. The sections were obtained with a benthos piston corer having an internal diameter of 5.5 cm. Site 31 (latitude 79° 08.7'N longitude 73° 23.9'W) is about 32 km east of Bache Peninsula and Site 32 (latitude 78° 39.9'N, longitude 72° 07.5'W) is located approximately 10 km northwest of Inglefield Land (Fig. 2). Water depths at Sites 31 and 32 are 185 and 377 m, respectively.

The cored sections were stored at room temperature after they were taken off the ship. The sediments were dry when sampled except for the upper 131.7 cm of the section from Site 32 which was still moist. The length of the dried section from Site 31 (253.7 cm) is 5.3 cm shorter than the length measured on board ship and the length of the partially dried section from Site 32 (280.2 cm) is 10.8 cm shorter than that measured on board ship. The discrepancies between the measurements made on board ship and those made twelve years later are related to shrinkage during storage.

METHODS

The colours of the wet and dry sediments from the sections were determined with the aid of the Geological Society of America Rock-Color Chart (Goddard et al., 1948). Both sections were sampled at 3 cm intervals, where possible. The number of samples from the sections at Sites 31 and 32 are 82 and 92, respectively. Grain-size data were obtained for two bulk samples from the lower part of the section from Site 32. The first sample is from the interval 202.7 - 215.7 cm and the second sample is from the interval 258.7 - 280.2 cm. Pebbles were removed from the samples before the analyses. The grain-size analyses were done at the Geological Survey of Canada, Ottawa, Ontario.

A portion of each sample from the cored sections was used for microfaunal analysis, following the procedure outlined by Rodrigues and Richard (1986). The microfaunal samples were air dried, weighed and disaggregated by soaking in water. The slurry was washed by hand in running water in a 63 μm sieve to remove the silt and clay fractions. After most of the silt and clay were washed out, the residue was cleaned ultrasonically, dried and weighed. The washed residues were scanned and variations in the proportions of benthonic foraminiferal species were estimated visually. There was no significant variation in species abundances in the samples from Site 31. Samples were selected for quantitative analysis at about 15 cm intervals to show the distribution of foraminifers in the section. The abundances of some benthonic foraminiferal species varied significantly in the cored section from Site 32. Therefore, samples were selected to document the variation in species abundances.

The samples selected for quantitative analysis were sieved using 850, 425, 250, 180, 150 and 75 μm sieves. Foraminifers were picked from each sieve fraction and mounted on standard 60-grid micropaleontological slides. The residue in some sieves contained large amounts of sand-size particles. For those sieve fractions foraminiferal tests were concentrated by floatation using a mixture of tetrabromoethane and acetone, density 1.9 g/cm^3. Benthonic foraminifers were identified to specific level in most cases. Some benthonic foraminifers were identified to generic level. Species of the Family Polymorphinidae were present in low numbers in only a few samples and are grouped under Polymorphinid. References for the foraminifers identified to specific level are given in Appendix I.

Two sets of counts were obtained for species and Polymorphinid in the samples from Site 31. Set 1 consists of counts of tests in the 850, 425, 250, 180 and 150 μm sieves and set 2 consists of counts of tests in the 850, 425, 250, 180, 150 and 75 μm sieves. The counts for each set were converted to percent abundances to determine if there is a significant difference in species abundances between the two sets of counts. The counts and percent abundances of ~~species~~ and Polymorphinid in the samples from Site 32 are based on tests in the 850, 425, 250, 180, 150 and 75 μm sieves.

Planktonic foraminifers accompanying the benthonic foraminifers were identified and the number of planktonic foraminiferal tests in the samples were recorded. Benthonic foraminiferal species with abundances greater than 4% are termed characteristic species and those with abundances less than 4% are termed subordinate species.

Benthonic foraminiferal diversities were computed using the Shannon-Wiener Information Function, $H(S) = -\sum_{i=1}^{S} p_i \ln p_i$, where H(S) is the diversity, S is the number of species plus Polymorphinid in the sample, p_i is the proportion of the *i*th species or Polymorphinid and ln is the natural logarithm. The minimum value of H(S) is 0.00 for S equals to 1. The maximum value of H(S) for a given S occurs when all S species and Polymorphinid are equally distributed.

Radiocarbon age determinations were obtained on benthonic foraminifers from the lower part of each section and an unidentified pelecypod valve from the upper part of the cored section from Site 31. The radiocarbon age determinations were carried out at IsoTrace Laboratory, University of Toronto (Appendix II).

RESULTS

Site 31

The cored section from Site 31 consists of light olive gray (5 Y 6/1), fossiliferous, poorly sorted, pebbly, sandy mud. Pebbles are most abundant in the upper part of the section and some pebbles are striated. Shell (pelecypod ?) and coal fragments are present throughout the section. A radiocarbon date of 3310 ± 70 years BP (TO-567) was obtained on a pelecypod valve from the upper part of the section (55.2 - 57.2 cm) and a date of 9170 ± 130 years BP (TO-771) was obtained on benthonic foraminifers from the lower part of the section (249.2 - 253.7 cm; Fig. 4).

The benthonic foraminiferal fauna from 16 samples used for quantitative analysis consists of 68 calcareous species excluding Polymorphinid and 9 agglutinated species. Calcareous species are ubiquitous in the samples, whereas agglutinated species are only present in the upper part of the section. A total of 62 845 benthonic foraminiferal tests were counted from residues ≥75 μm. Only one planktonic species, Neogloboquadrina pachyderma (Ehrenberg), is present in the samples. A total of 6564 tests of the planktonic species were counted; 6345 (96.7%) are sinistrally coiled and 219 (3.3%) are dextrally coiled. The number of benthonic and planktonic foraminiferal tests, the number of benthonic foraminiferal species and the benthonic foraminiferal diversity for each sample are listed in Table 2. The percent abundances of benthonic foraminifers in the samples are listed in Table 3 (in pocket).

Cassidulina reniforme Nørvang, Elphidium excavatum (Terquem) forma clavata Cushman, Cibicides lobatulus (Walker and Jacob), Cassidulina teretis Tappan and Islandiella norcrossi (Cushman) are the characteristic benthonic

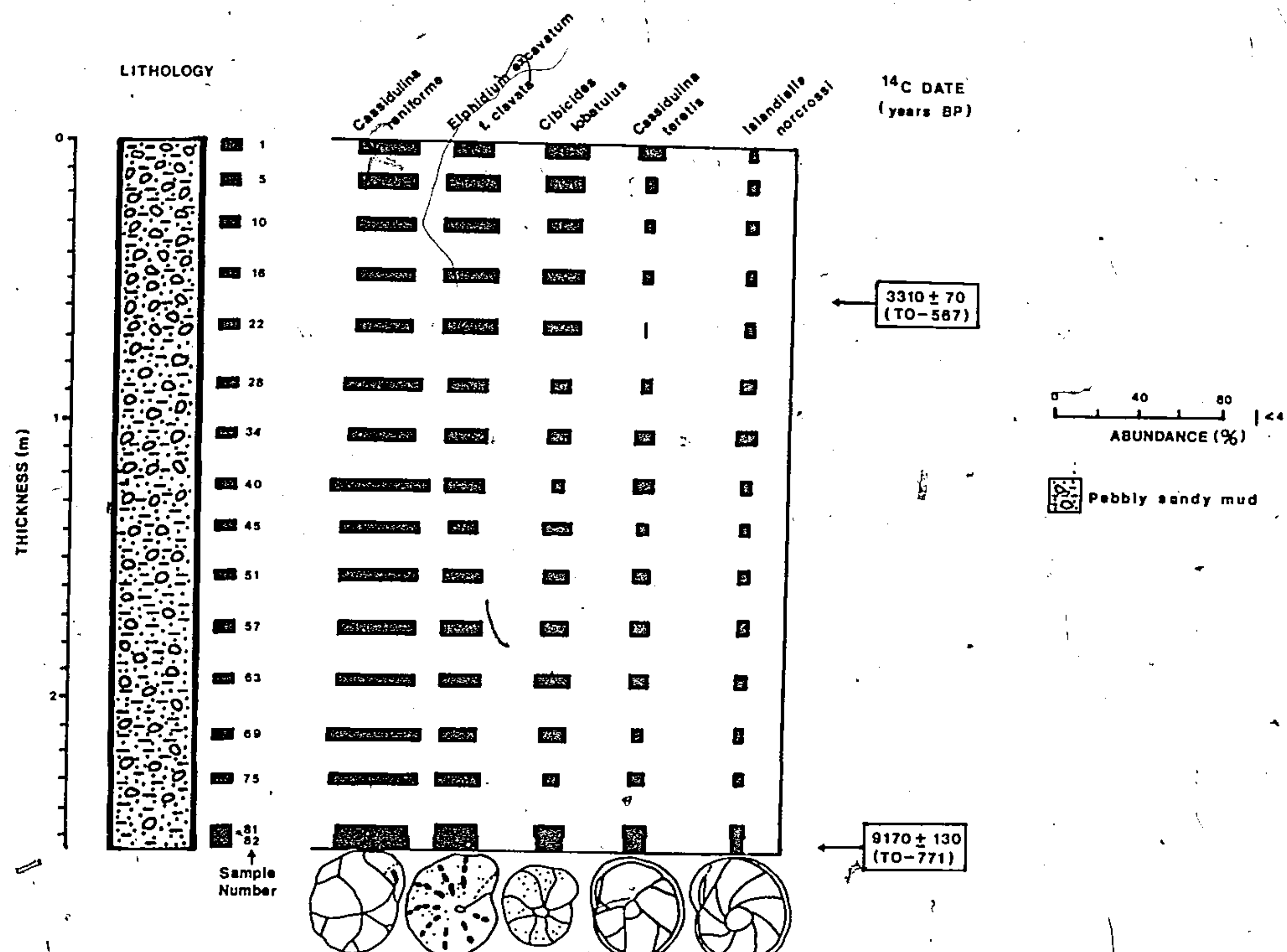

Figure 4: Percent abundances of characteristic benthonic foraminiferal species ≥ 75 µm in samples from section at Site 31.

Table 2: Foraminiferal and lithologic data for samples from Site 31. Foraminiferal data based on residues ≥75 µm. Sample intervals are measured from top of section.

					Foraminiferida					
					Benthonic				Planktonic[1]	
					Number of Tests				Number of Tests	
Sample Number	Sample Interval (cm)	Lithology	Colour[2] Dry	Weight of Sediment Processed (g)	Agglutinated	Calcareous	Number of Species (S)	Diversity [H(S)]	Sinistral	Dextral
1	0 - 3.5	Pebbly sandy mud	5 Y 6/1	40.7	314	18674	57	2.13	2331	72
5	12.5 - 15.5	Pebbly sandy mud	5 Y 6/1	21.6	2	4379	37	2.09	314	11
10	27.5 - 31.2	Pebbly sandy mud	5 Y 6/1	21.0	0	5064	36	2.10	297	11
16	46.2 - 49.2	Pebbly sandy mud	5 Y 6/1	20.3	0	1927	33	2.10	99	4
22	64.2 - 68.2	Pebbly sandy mud	5 Y 6/1	24.2	8	3955	39	2.15	187	7
28	85.2 - 88.2	Pebbly sandy mud	5 Y 6/1	27.8	0	1105	29	2.07	74	6
34	103.2 - 106.2	Pebbly sandy mud	5 Y 6/1	34.0	0	1144	26	2.09	110	6
40	122.2 - 125.2	Pebbly sandy mud	5 Y 6/1	41.6	0	5852	41	1.86	619	23
45	135.7 - 138.7	Pebbly sandy mud	5 Y 6/1	33.6	0	1424	35	2.19	115	5
51	153.7 - 156.7	Pebbly sandy mud	5 Y 5/1	29.1	0	2372	34	2.01	315	12
57	171.7 - 175.7	Pebbly sandy mud	5 Y 6/1	35.6	0	2234	32	2.03	242	7
63	191.2 - 194.2	Pebbly sandy mud	5 Y 6/1	32.0	0	3417	32	1.88	479	23
69	210.2 - 213.2	Pebbly sandy mud	5 Y 6/1	30.4	0	1050	33	2.02	68	1
75	228.2 - 231.2	Pebbly sandy mud	5 Y 6/1	25.5	0	1241	26	1.93	142	3
81	246.2 - 249.2	Pebbly sandy mud	5 Y 6/1	55.2	0	4325	37	2.12	517	15
82	249.2 - 253.7	Pebbly sandy mud	5 Y 6/1	61.6	0	4358	35	2.05	436	13

[1] Neogloboquadrina pachyderma (Ehrenberg) is the only species present.

[2] Colour determined using the Geological Society of America Rock-Color Chart.

Table 3: Percent abundances of benthonic foraminifers $\geq$75 μm in sa

Species	1	5	10	16	22	28	34
Adercotryma glomerata (Brady)	0.82	0.05			0.10		
Astacolus hyalacrulus Loeblich and Tappan							
Astrononion gallowayi Loeblich and Tappan	2.02	2.03	1.96	1.87	2.22	4.89	3.33
Bathysiphon sp.	0.01						
Bolivina sp. A							
Bolivina sp. B							
Buccella arctica Voloshinova	1.51	2.63	2.94	2.65	3.08	3.62	2.63
Buccella calida (Cushman and Cole)	0.03	0.05	0.06	0.26	0.08		0.26
Buccella frigida (Cushman)	1.27	1.35	1.99	1.30	2.32	0.91	0.88
Buccella tenerrima (Bandy)	1.23	1.39	1.34	1.09	1.79	0.27	0.44
Buccella sp.							
Bulimina aculeata d'Orbigny	0.01		0.02				
Buliminella hensoni Lagoe	0.02		0.02				
Cassidulina reniforme Nørvang	28.70	28.40	27.82	28.28	27.28	38.19	31.87
Cassidulina teretis Tappan	12.06	5.30	4.70	4.93	2.78	5.70	9.02
Cibicides lobatulus (Walker and Jacob)	20.57	18.72	17.02	18.89	18.52	8.51	10.86
Cribrostomoides crassimargo (Norman)	0.01						
Cribrostomoides jeffreysi (Williamson)	0.23				0.03		
Dentalina frobisherensis Loeblich and Tappan					0.03		
Elphidiella arctica (Parker and Jones)	0.32	0.18	0.32	0.83	0.61	0.18	
Elphidium bartletti Cushman	0.02		0.02	0.05		0.09	
Elphidium excavatum (Terquem) forma clavata Cushman	19.28	24.93	25.79	25.43	25.08	18.91	21.80
Elphidium subarcticum Cushman	2.12	2.05	2.76	2.13	4.34	2.26	0.61
Elphidium sp. A	0.11	0.64	0.57	0.16	0.30		0.09
Elphidium sp. B	0.09	0.[illegible]2	0.02	0.31	0.10		0.26
Elphidium sp. C	0.01						
Elphidium sp. D							
Eoeponidella pulchella (Parker)	0.93	0.87	0.81	1.35	1.56	0.18	0.35
Epistominella arctica Green	0.03					0.09	
Fissurina cucurbitasema Loeblich and Tappan	0.01						
Fissurina marginata (Montagu)	0.15	0.05				0.09	
Fissurina reniformis (Sidebottom)						0.09	
Fissurina ventricosa (Wiesner)		0.02	0.02		0.05	0.09	
Fissurina sp. A	0.01	0.02	0.04				
Fissurina sp. B	0.28	0.23	0.16	0.16	0.40		0.35
Fissurina sp. C	0.01						
Fursenkoina loeblichi (Feyling-Hanssen)	0.88	1.10	1.24	1.09	1.26	1.27	0.96
Fursenkoina sp.	0.03						
Glabratella sp.	0.03		0.02	0.05	0.05	0.09	0.09
Glandulinoides ittai (Loeblich and Tappan)		0.02					
Haynesina orbicularis (Brady)	0.08	0.30	0.26	0.31	0.33	1.09	1.05
Haynesina sp.	0.20	0.37	0.10	0.47	0.25	0.27	
Islandiella helenae Feyling-Hanssen and Buzas	0.58	1.69	1.64	1.04	0.93	2.90	3.24
Islandiella islandica (Nørvang)	0.21	0.41	0.22	0.16	0.20	0.81	1.23
Islandiella norcrossi (Cushman)	4.16	6.03	6.77	5.71	4.79	8.33	9.72
Lagena laevis (Montagu)			0.02				0.09
Lagena meridionalis Wiesner	0.02	0.02	0.02	0.10			
Lenticulina sp.	0.01						
Melonis zaandami (van Voorthuysen)	0.22	0.32	0.26	0.16	0.30		0.18
Nodosaria sp.					0.03		
Nonionellina labradorica (Dawson)	0.21	0.11	0.18	0.16	0.18	0.36	0.35
Oolina acuticostata (Reuss)	0.02				0.03		
Oolina caudigera (Wiesner)							
Oolina hexagona (Williamson)		0.02		0.05			
Oolina lineata (Williamson)							
Oolina melo d'Orbigny	0.02	0.02			0.05		
Oolina striatopunctata (Parker and Jones)	0.01		0.04				
Oolina williamsoni (Alcock)	0.03	0.07			0.05	0.09	0.09
Parafissurina fovigera (Buchner)						0.09	
Parafissurina sp.	0.02						
Patellina corrugata Williamson	0.04			0.05	0.03		
Pateoris hauerinoides (Rhumbler)							
[1]Polymorphinid	0.01	0.05		0.10		0.09	
Pseudoparrella takayanagii (Iwasa)	0.14	0.16	0.34	0.21	0.23	0.36	0.18
Pyrgo williamsoni (Sylvestri)							
Quinqueloculina agglutinata Cushman							
Quinqueloculina arctica Cushman							
Quinqueloculina stalkeri Loeblich and Tappan							
Robertinoides suecicum Höglund							
Rosalina sp.	0.16	0.05	0.08	0.26	0.10		
Spiroplectammina biformis (Parker and Jones)	0.01				0.03		
Stetsonia horvathi Green	0.04						
Textularia torquata Parker	0.18				0.05		
Trifarina hughesi (Galloway and Wissler)	0.23	0.27	0.38	0.26	0.43		0.09
Triloculina trihedra Loeblich and Tappan	0.26	0.09	0.06	0.16	0.03	0.18	
Trochammina nana (Brady)	0.35						
Trochammina quadriloba Höglund	0.02						
Trochammina sp.	0.03						
Number of species	57	37	36	33	39	29	26

[1]Includes species of the Family Polymorphinidae.

ers $\geq$75 μm in samples from Site 31.

Sample Number												
6	22	28	34	40	45	51	57	63	69	75	81	82
	0.10											
				0.02								
87	2.22	4.89	3.33	2.68	4.35	3.08	3.18	1.52	4.48	4.19	2.66	2.59
				0.05	0.14							
						0.04		0.03				
.65	3.08	3.62	2.63	1.76	2.53	1.73	2.15	2.31	1.90	2.34	2.17	2.13
.26	0.08		0.26	0.17		0.08	0.27	0.20	0.29	0.08	0.25	0.21
.30	2.32	0.91	0.88	0.36	1.40	0.59	0.36	0.15	0.57	0.64	1.04	0.73
.09	1.79	0.27	0.44	0.17	1.05	0.46	0.40	0.44	0.19		0.42	0.21
								0.03				
					0.07							
				0.58		0.04						
.28	27.28	38.19	31.87	47.03	37.22	39.33	36.93	37.58	42.19	40.53	32.62	35.36
.93	2.78	5.70	9.02	8.41	6.18	8.22	8.42	8.52	4.48	7.82	10.52	9.91
.89	18.52	8.51	10.86	7.45	14.82	12.90	13.07	17.38	11.62	7.90	14.38	11.91
	0.03											
	0.03											
.83	0.61	0.18		0.07	0.35	0.13	0.22	0.09	0.48		0.12	0.28
.05		0.09		0.02	0.14		0.09	0.03	0.19	0.40	0.09	0.21
.43	25.08	18.91	21.80	18.71	14.40	18.59	19.92	19.61	17.52	22.64	18.64	21.32
.13	4.34	2.26	0.61	0.50	0.49	0.25	0.27	0.06	0.57	0.08	1.04	1.45
.16	0.30		0.09									0.02
.31	0.10		0.26		0.07	0.38	0.18	0.09	0.19	0.16	0.07	
											0.05	
.35	1.56	0.18	0.35	0.89	0.49	0.80	0.58	0.56	0.29		0.99	0.69
		0.09		0.07	0.14		0.04					
		0.09			0.07	0.04					0.05	
		0.09										
	0.05	0.09		0.02								
.16	0.40		0.35	0.17	0.14	0.59	0.31		0.19	0.16	0.44	0.16
.09	1.26	1.27	0.96	0.75	1.05	1.01	0.67	0.82	0.57	0.81	0.79	0.85
									0.10			
.05	0.05	0.09	0.09	0.05	0.14	0.04		0.03	0.10			0.02
.31	0.33	1.09	1.05	0.85	1.19	1.26	1.75	1.29	2.38	1.53	0.88	0.94
.47	0.25	0.27		0.10	0.49	0.17	0.09	0.06	0.29	0.32	0.19	0.28
.04	0.93	2.90	3.24	1.23	2.25	1.22	2.19	1.52	2.29	2.82	3.12	2.75
.16	0.20	0.81	1.23	0.56	2.18	1.39	1.43	1.00	2.57	1.21	0.86	0.62
.71	4.79	8.33	9.72	5.01	5.48	5.90	5.86	6.09	4.95	4.83	7.24	5.92
			0.09									
.10				0.02	0.07	0.04		0.06			0.02	
.16	0.30		0.18	0.09	0.56	0.17	0.22	0.09	0.19	0.08	0.16	0.21
	0.03											
.16	0.18	0.36	0.35	0.55	0.21	0.17	0.31	0.03	0.19	0.24	0.28	0.23
	0.03					0.04		0.03	0.10		0.02	
				0.03			0.04		0.10			0.02
.05				0.03			0.04				0.02	0.02
							0.04	0.03			0.02	0.02
	0.05										0.02	0.02
	0.05	0.09	0.09	0.05			0.04					0.07
		0.09						0.03			0.02	
					0.07							
.05	0.03			0.07		0.04						0.02
				0.02					0.10		0.05	0.02
.10		0.09		0.10	0.07					0.16	0.02	
.21	0.23	0.36	0.18	0.21	0.21	0.25	0.18	0.09	0.29	0.32	0.30	0.28
				0.05								
										0.08	0.02	
				0.02	0.07							
						0.04			0.10			
							0.04					
.26	0.10											
	0.03											
				0.67	1.47	0.51	0.54	0.18	0.38	0.32	0.19	0.11
	0.05											
.26	0.43		0.09	0.02	0.28	0.25	0.13	0.09	0.10	0.08		0.25
.16	0.03	0.18		0.41	0.14	0.21			0.10	0.24	0.23	0.16
33	39	29	26	41	35	34	32	32	33	26	37	35

foraminiferal species of the assemblages (Fig. 4). The range and mean percent abundances of the characteristic benthonic species are listed in Table 4. The cored section from Site 31 was not divided into zones because the benthonic foraminiferal assemblages do not vary significantly from the base to the top of the section. The ubiquitous subordinate benthonic foraminiferal species are listed in Table 5 and the distribution of selected subordinate species which occur in some of the samples is shown in Figure 5.

The total number of benthonic foraminiferal tests is lower in the 850 to 150 µm sieves (19 059) in comparison to the total number of tests of benthonic foraminifers in the 850 to 75 µm sieves (62 845). Similarly, the total number of planktonic foraminiferal tests is lower in the 850 to 150 µm sieves (3149) in comparison to the total number of tests of planktonic foraminifers in the 850 to 75 µm sieves (6564). Sixty-two benthonic foraminiferal species including Polymorphinid and one planktonic species (Neogloboquadrina pachyderma) were identified in residues ≥150 µm. The number of tests of benthonic and planktonic foraminifers, the number of benthonic foraminiferal species and the benthonic foraminiferal diversity for each sample are listed in Table 6. The percent abundances of benthonic foraminifers in the samples are listed in Table 7 (in pocket).

Cibicides lobatulus, Elphidium excavatum forma clavata, Islandiella norcrossi, Cassidulina teretis, Cassidulina reniforme and Islandiella helenae Feyling-Hanssen and Buzas

Table 4: Range and mean percent abundances of characteristic benthonic foraminiferal species in sixteen samples from Site 31 in residues ≥ 75 µm and ≥ 150 µm.

Species	Abundance (%)					
	Residue ≥ 75 µm			Residue ≥ 150 µm		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Cassidulina reniforme Nørvang	27.28	47.03	34.96	3.45	15.08	7.24
Elphidium excavatum (Terquem) forma *clavata* Cushman	14.40	25.79	20.79	2.24	24.42	19.45
Cibicides lobatulus (Walker and Jacob)	7.45	20.57	14.03	17.82	40.89	29.75
Cassidulina teretis Tappan	2.78	12.06	7.31	3.20	16.37	9.94
Islandiella norcrossi (Cushman)	4.16	9.72	6.05	6.64	18.18	11.21
Islandiella helenae Feyling-Hanssen and Buzas	0.58	3.24	1.96	1.34	9.27	5.07

Table 5: Ubiquitous subordinate benthonic foraminiferal species $\geq$75 μm at Site 31.

Astrononion gallowayi Loeblich and Tappan
Buccella arctica Voloshinova
Buccella calida (Cushman and Cole)
Buccella frigida (Cushman)
Buccella tenerrima (Bandy)
Elphidiella arctica (Parker and Jones)
Elphidium subarcticum Cushman
Eoeponidella pulchella (Parker)
Fissurina sp. B
Fursenkoina loeblichi (Feyling-Hanssen)
Haynesina orbicularis (Brady)
Haynesina sp.
Islandiella helenae Feyling-Hanssen and Buzas
Islandiella islandica (Nørvang)
Melonis zaandami (Van Voorthuysen)
Nonionellina labradorica (Dawson)
Pseudoparrella takayanagii (Iwasa)
Trifarina hughesi (Galloway and Wissler)
Triloculina trihedra Loeblich and Tappan

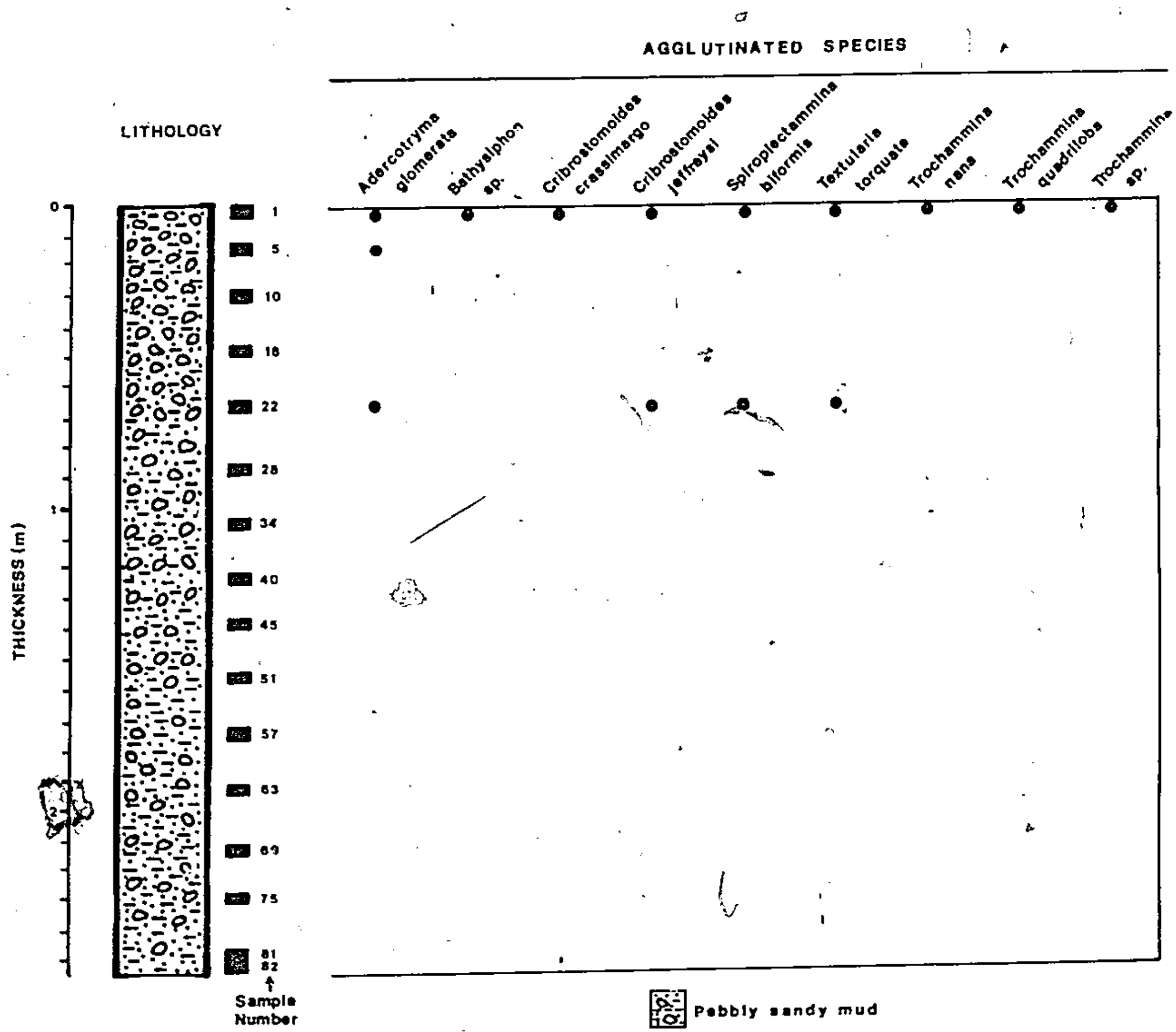

Figure 5: Distribution of selected subordinate benthonic foraminiferal species ≥ 75 µm at Site 31.

Table 6: Foraminiferal and lithologic data for samples from Site 31. Foraminiferal data based on residues $\geq$150 μm. Sample intervals are measured from the top of section.

					Foraminiferida					
					Benthonic				Planktonic[1]	
					Number of Tests				Number of Tests	
Sample Number	Sample Interval (cm)	Lithology	Colour[2] Dry	Weight of Sediment Processed (g)	Agglutinated	Calcareous	Number of Species (S)	Diversity [H(S)]	Sinistral	Dextral
1	0 - 3.5	Pebbly sandy mud	5 Y 6/1	40.7	70	6477	43	2.05	1217	33
5	12.5 - 15.5	Pebbly sandy mud	5 Y 6/1	21.6	1	1706	28	2.10	177	6
10	27.5 - 31.2	Pebbly sandy mud	5 Y 6/1	21.0	0	1622	26	2.14	136	7
16	46.2 - 49.2	Pebbly sandy mud	5 Y 6/1	20.3	0	615	25	2.07	56	3
22	64.2 - 68.2	Pebbly sandy mud	5 Y 6/1	24.2	0	1187	26	2.21	107	4
28	85.2 - 88.2	Pebbly sandy mud	5 Y 6/1	27.8	0	309	20	2.26	36	2
34	103.2 - 106.2	Pebbly sandy mud	5 Y 6/1	34.0	0	341	21	2.15	37	4
40	122.2 - 125.2	Pebbly sandy mud	5 Y 6/1	41.6	0	1326	30	2.25	223	6
45	135.7 - 138.7	Pebbly sandy mud	5 Y 6/1	33.6	0	313	24	2.20	46	2
51	153.7 - 156.7	Pebbly sandy mud	5 Y 6/1	29.1	0	656	22	2.16	159	6
57	171.1 - 175.2	Pebbly sandy mud	5 Y 6/1	35.6	0	575	23	2.20	108	3
63	191.2 - 194.2	Pebbly sandy mud	5 Y 6/1	32.0	0	937	22	1.89	262	12
69	210.2 - 213.2	Pebbly sandy mud	5 Y 6/1	30.4	0	315	25	2.33	24	0
75	228.2 - 231.2	Pebbly sandy mud	5 Y 6/1	25.5	0	303	19	2.25	48	1
81	246.2 - 249.2	Pebbly sandy mud	5 Y 6/1	55.2	0	982	27	2.14	187	5
82	249.2 - 253.7	Pebbly sandy mud	5 Y 6/1	61.6	0	1324	26	2.22	225	7

[1] *Neogloboquadrina pachyderma* (Ehrenberg) is the only species present.

[2] Colour determined using the Geological Society of America Rock-Color Chart.

Table 7: Percent abundances of benthonic foraminifers $\geq$150 µm in s

Species	1	5	10	16	22	28	
Adercotryma glomerata (Brady)	0.79	0.06					
Astacolus hyalacrulus Loeblich and Tappan							
Astrononion gallowayi Loeblich and Tappan	1.19	1.35	1.60	0.98	0.59	2.27	
Bathysiphon sp.	0.03						
Buccella arctica Voloshinova	1.45	1.46	1.42	1.63	1.85	1.62	
Buccella calida (Cushman and Cole)							
Buccella frigida (Cushman)	0.53	1.05	2.16	1.14	2.61	0.65	
Buccella tenerrima (Bandy)	3.18	3.34	4.19	3.41	5.98	0.97	
Bulimina aculeata d'Orbigny			0.06				
Buliminella hensoni Lagoe	0.05						
Cassidulina reniforme Nørvang	5.32	5.98	4.56	5.37	3.45	8.74	
Cassidulina teretis Tappan	3.41	6.85	6.47	4.39	3.20	9.06	1
Cibicides lobatulus (Walker and Jacob)	9.07	32.63	33.35	35.45	31.59	19.09	2
Cribrostomoides crassimargo (Norman)	0.02						
Cribrostomoides jeffreysi (Williamson)	0.17						
Dentalina frobisherensis Loeblich and Tappan					0.08		
Elphidiella arctica (Parker and Jones)	0.92	0.47	0.99	2.60	2.02	0.65	
Elphidium bartletti Cushman	0.05		0.06	0.16		0.32	
Elphidium excavatum (Terquem) forma clavata Cushman	8.45	24.02	21.33	23.25	21.74	22.33	2[illegible]
Elphidium subarcticum Cushman	3.30	3.57	4.44	3.74	8.51	3.56	[illegible]
Elphidium sp. A	0.32	1.58	1.54	0.49	1.01		[illegible]
Elphidium sp. B	0.27	0.06	0.06	0.98	0.34		[illegible]
Elphidium sp. C	0.02						
Elphidium sp. D							
Eoeponidella pulchella (Parker)							
Epistominella arctica Green	0.08						
Fissurina marginata (Montagu)	0.23						
Fissurina ventricosa (Wiesner)							
Fissurina sp. A	0.20	0.60					
Fissurina sp. B	0.40	0.41	0.25	0.49	0.76		[illegible]
Fursenkoina loeblichi (Feyling-Hanssen)	0.22	0.35	0.25			0.32	
Fursenkoina sp.	0.06						
Haynesina orbicularis (Brady)	0.14	0.06	0.37	0.16	1.10	1.94	[illegible]
Haynesina sp.	0.03						
Islandiella helenae Feyling-Hanssen and Buzas	1.34	3.51	2.90	2.28	2.36	7.77	[illegible]
Islandiella islandica (Nørvang)	0.40	0.64	0.62	0.33	0.67	2.27	[illegible]
Islandiella norcrossi (Cushman)	6.64	10.90	11.84	11.54	9.86	16.50	1[illegible]
Lagena laevis (Montagu)			0.06				[illegible]
Lagena meridionalis Wiesner		0.06					
Lenticulina sp.	0.03						
Melonis zaandami (van Voorthuysen)	0.16	0.53	0.68	0.49	0.93		[illegible]
Nodosaria sp.					0.08		
Nonionellina labradorica (Dawson)	0.24	0.23	0.25	0.33	0.34	0.97	[illegible]
Oolina acuticostata (Reuss)	0.05				0.08		
Oolina caudigera (Wiesner)							
Oolina hexagona (Williamson)		0.06		0.16			
Oolina lineata (Williamson)							
Oolina melo d'Orbigny	0.03				0.08		
Oolina striatopunctata (Parker and Jones)	0.02		0.12				
Oolina williamsoni (Alcock)	0.09	0.18			0.17	0.32	[illegible]
Parafissurina sp.	0.05						[illegible]
Patellina corrugata Williamson	0.05			0.16			
Pateoris hauerinoides (Rhumbler)							
Polymorphinid[1]		0.12		0.16		0.32	
Pseudoparrella takayanagii (Iwasa)							
Pyrgo williamsoni (Sylvestri)							
Quinqueloculina agglutinata Cushman							
Quinqueloculina arctica Cushman							
Stetsonia horvathi Green	0.03						
Trifarina hughesi (Galloway and Wissler)	0.46	0.35	0.31	0.16	0.51		0
Triloculina trihedra Loeblich and Tappan	0.23	0.12	0.12	0.16	0.09	0.32	
Trochammina nana (Brady)	0.06						
Number of species	43	28	26	25	26	20	2

[1]Includes species of the Family Polymorphinidae.

inifers ≥150 μm in samples from Site 31.

Sample Number													
10	16	22	28	34	40	45	51	57	63	69	75	81	82
					0.08								
1.60	0.98	0.59	2.27	1.76	2.34	3.51	1.22	1.22	0.96	3.17	2.97	1.73	2.04
1.42	1.63	1.85	1.62	0.59	1.51	0.32	1.22	0.87	0.53	0.95	1.32	0.61	1.28
									0.21	0.32			
2.16	1.14	2.61	0.65	0.29	0.38	0.96	0.30				0.99	0.81	0.15
4.19	3.41	5.98	0.97	1.17	0.75	1.92	1.52	1.57	1.60	0.63		1.83	0.68
0.06						0.32							
4.56	5.37	3.45	8.74	4.40	15.08	9.27	9.30	8.17	6.40	9.52	7.92	4.68	7.63
6.47	4.39	3.20	9.06	13.78	16.37	5.34	13.26	10.09	9.71	6.98	15.84	10.29	13.97
33.35	35.45	31.59	19.09	21.41	18.70	40.89	27.90	29.57	39.49	27.62	17.82	36.86	24.55
		0.08											
0.99	2.60	2.02	0.65		0.30	1.60	0.46	0.87	0.32	1.59		0.51	0.91
0.06	0.16		0.32		0.08	0.64		0.35	0.11	0.63	1.65	0.41	0.68
21.33	23.25	21.74	22.33	20.82	20.21	2.24	20.58	20.17	20.17	19.05	24.42	11.81	20.54
4.44	3.74	8.51	3.56	0.29	1.96	2.24	0.91	1.04	0.21	1.90	0.33	2.65	3.70
1.54	0.49	1.01		0.29									0.08
0.06	0.98	0.34		0.88		0.32	1.37	0.70	0.32	0.63	0.66	0.31	
												0.20	
												0.10	0.08
						0.32						0.10	
					0.08								
0.25	0.49	0.76		0.59	0.75	0.64	1.22	0.70		0.32	0.33	0.51	0.15
0.25			0.32		0.45	0.32	0.15			0.32		0.10	0.23
0.37	0.16	1.10	1.94	2.35	1.73	2.88	1.07	1.57	1.71	2.54	4.29	0.71	1.06
						0.32		0.35					
2.90	2.28	2.36	7.77	8.80	4.15	5.75	3.51	6.43	3.52	5.71	6.93	9.27	6.87
0.62	0.33	0.67	2.27	2.64	1.96								
11.84	11.54	9.86	16.50	18.18	10.94	10.86	10.52	9.74	11.31	8.57	8.58	11.71	11.71
0.06				0.29									
					0.08				0.11				
0.68	0.49	0.93		0.59	0.38	2.56	0.30	0.70	0.32	0.63		0.71	0.68
		0.08											
0.25	0.33	0.34	0.97	0.29			0.30	0.70	0.11	0.63	0.33	0.41	0.45
		0.08					0.15		0.11	0.32		0.10	
					0.15			0.17		0.32			0.08
	0.16				0.15							0.10	
								0.17	0.11			0.10	
		0.08											0.08
0.12													
		0.17	0.32	0.29	0.23			0.17					0.23
	0.16												
					0.08								
	0.16		0.32							0.32	0.66		
					0.08								
					0.23								
											0.33	0.10	
					0.08	0.32							
0.31	0.16	0.51		0.29	0.08		0.30	0.35	0.21	0.32			0.45
0.12	0.16	0.09	0.32		0.68	0.32	0.30			0.32	0.33		0.08
26	25	26	20	21	30	24	22	23	22	25	19	27	26

are the characteristic benthonic foraminiferal species of the assemblages based on the ≥150 μm residues (Fig. 6). The range and mean percent abundances of the characteristic benthonic species in residues ≥150 μm are listed in Table 4.

Site 32

Three lithologic units are recognized for the cored section from Site 32. Unit 1 (199.7 - 280.2 cm) is pale red (10 R 6/2), unfossiliferous, poorly sorted, pebbly sand. The pebbles in Unit 1 are commonly striated. Results of the grain-size analysis of the ≤2 mm fraction show that the lower part of Unit 1 (258.7 - 280.2 cm) consists of 71% sand, 15% silt and 14% clay and the upper part of the unit (202.7 - 215.7 cm) is composed of 67% sand, 17% silt and 16% clay. Unit 2 (173.7 - 199.7 cm) is pale red (10 R 6/2) to pale olive (10 Y 6/2), poorly sorted, pebbly, muddy sand and pebbly, sandy mud. Foraminifers and unidentified shell fragments (pelecypods ?) are present in Unit 2, however, the interval 196.7 - 199.7 cm is unfossiliferous. A radiocarbon date of 7590 ± 120 years BP (TO-770) was obtained on benthonic foraminifers from the middle part of Unit 2 (179.2 - 182.2 cm; Fig. 7). Unit 3 (0 - 173.2 cm) is a pale olive (10 Y 6/2; dry sediment colour) to light olive gray (5 Y 6/1; dry sediment colour), fossiliferous, massive mud with minor pebbles and sand. Shell fragments (pelecypods ?) are present in Unit 3. The upper 131.7 cm of Unit 3 contains gypsum crystals. Foraminifers are rare to absent in the gypsum-bearing interval.

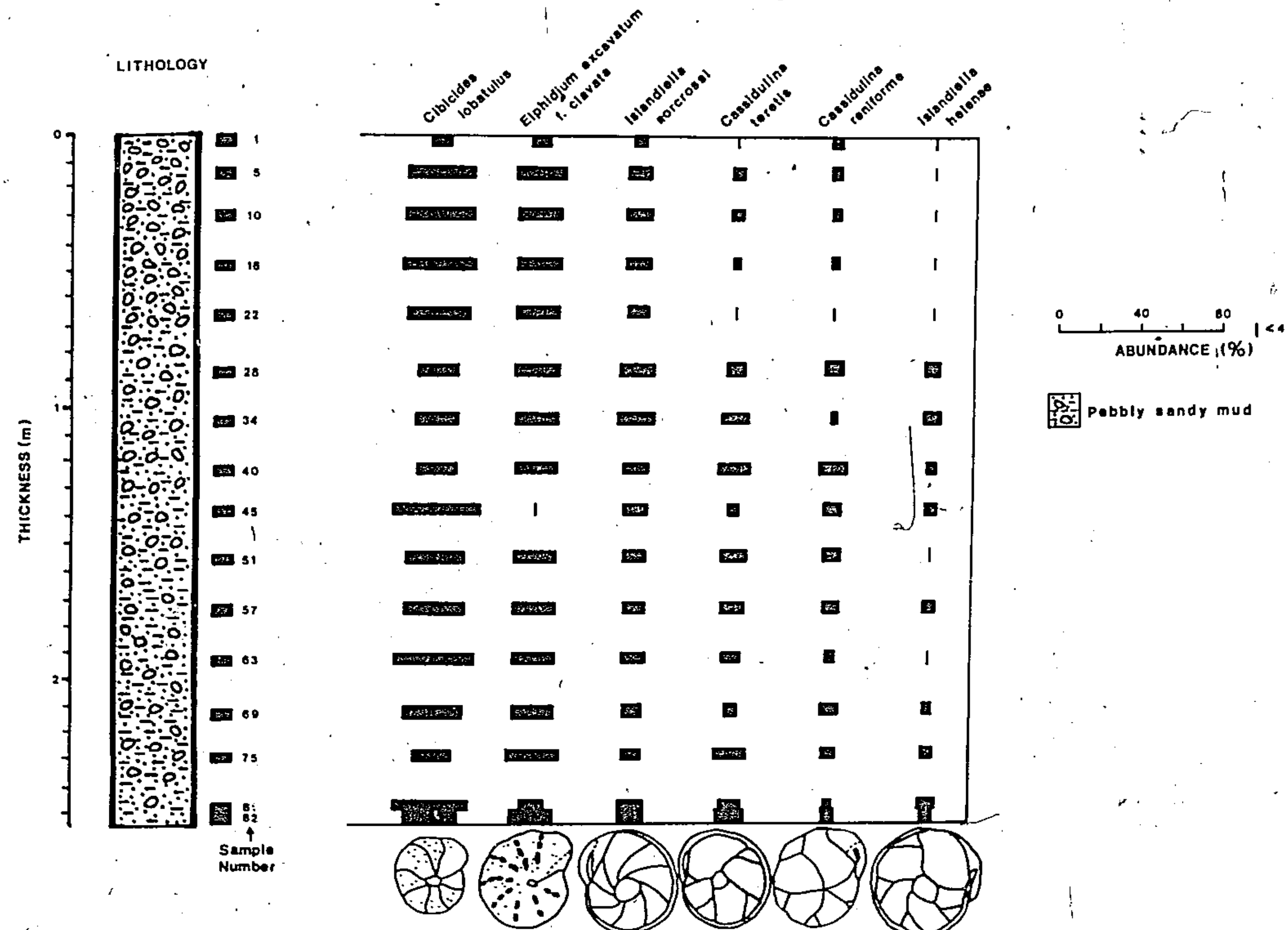

Figure 6: Percent abundances of characteristic benthonic foraminiferal species ≥150 μm in samples from section at Site 31.

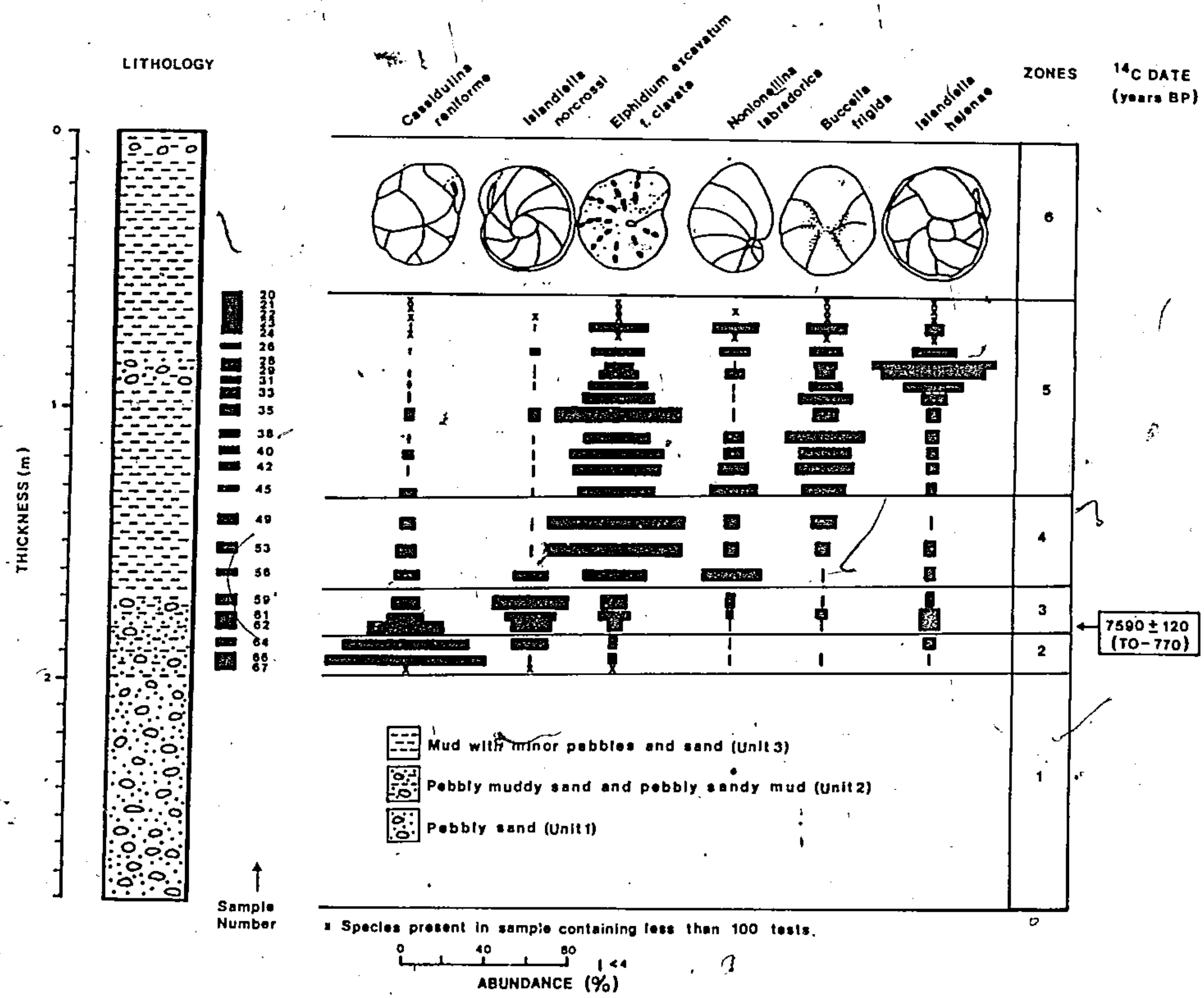

Figure 7: Percent abundances of characteristic benthonic foraminiferal species ≥75 µm in samples from section at Site 32.

Diatoms are present in Unit 3 between 0 and 157.2 cm and are most abundant in the interval containing gypsum.

The benthonic foraminiferal fauna from 24 samples used for quantitative analysis consists of 50 calcareous species excluding Polymorphinid. A total of 37 410 benthonic and 457 planktonic foraminiferal tests were counted from residues ≥75 μm. Only one planktonic foraminiferal species, Neogloboquadrina pachyderma, is present in the samples. The number of benthonic and planktonic foraminiferal tests, the number of benthonic foraminiferal species and the benthonic foraminiferal diversity for each sample are listed in Table 8. The percent abundances of benthonic foraminifers in the samples are listed in Table 9 (in pocket).

The section from Site 32 is divided into six zones on the basis of the distribution and abundance of benthonic foraminifers (Fig. 7). The oldest and youngest zones, Nos. 1 and 6 respectively, are characterized by the absence of foraminifers. Cassidulina reniforme is the most abundant species in Zone 2. The most abundant species in Zone 3 are Islandiella norcrossi and Cassidulina reniforme. Elphidium excavatum forma clavata and Nonionellina labradorica (Dawson) are the most abundant species in Zone 4 and Elphidium excavatum forma clavata, Buccella frigida (Cushman), Islandiella helenae and Nonionellina labradorica are the most abundant species in Zone 5. The range and mean percent abundances of the characteristic benthonic foraminiferal

Table 8: Microfaunal and lithologic data for samples from Site 32. Microfaunal data based on residues ≥ 75 µm. Sample intervals are measured from top of section.

						Foraminiferida						Diatoms
						Benthonic				Planktonic[1]		
			Colour[2]			Number of Tests				Number of Tests		
Sample Number	Sample Interval (cm)	Lithology	Wet	Dry	Weight of Sediment Processed (g)	Agglutinated	Calcareous	Number of Species (S)	Diversity[3] [H(S)]	Sinistral	Dextral	
20	59.0 - 62.0	Mud	5 Y 3/2	5 Y 6/1	22.5	0	30	8		1	0	X[4]
21	62.0 - 65.0	Mud	5 Y 3/2	5 Y 6/1	23.4	0	71	12		2	0	X
22	65.0 - 68.5	Mud	5 Y 3/2	5 Y 6/1	25.0	0	71	8		0	0	X
23	68.5 - 71.5	Mud	5 Y 3/2	5 Y 6/1	19.6	0	387	14	1.89	1	0	X
24	71.5 - 74.5	Mud	5 Y 3/2	5 Y 6/1	20.4	0	41	9		1	0	X
26	77.5 - 79.5	Mud	5 Y 3/2	5 Y 6/1	13.3	0	146	10	1.89	0	0	X
28	83.0 - 85.5	Pebbly sandy mud	5 Y 5/2	5 Y 6/1	25.1	0	347	13	1.40	0	0	X
29	85.5 - 87.5	Sandy mud	5 Y 5/2	5 Y 6/1	22.9	0	608	15	1.63	0	0	X
31	90.5 - 92.2	Pebbly mud	5 Y 5/2	10 Y 6/2	16.3	0	143	15	1.96	0	0	X
33	94.2 - 97.2	Mud	5 Y 3/2	10 Y 6/2	21.9	0	119	11	1.78	0	0	X
35	100.2 - 103.2	Mud	5 Y 3/2	10 Y 6/2	25.1	0	442	15	1.49	2	0	X
38	109.2 - 112.2	Mud	5 Y 3/2	10 Y 6/2	27.5	0	259	12	1.65	1	0	X
40	115.2 - 118.2	Mud	5 Y 3/2	10 Y 6/2	31.6	0	1090	16	1.66	2	0	X
42	121.2 - 124.2	Mud	5 Y 3/2	10 Y 6/2	22.1	0	367	11	1.56	1	0	X
45	130.2 - 131.7	Mud	5 Y 3/2	10 Y 6/2	14.9	0	476	12	1.69	0	0	X
49	140.7 - 143.7	Mud		10 Y 6/2	27.5	0	3530	17	1.32	34	0	X
53	151.2 - 154.2	Mud		10 Y 6/2	27.0	0	4781	19	1.35	22	1	X
56	160.2 - 163.2	Mud		10 Y 6/2	30.2	0	7509	23	1.75	20	1	
59	169.7 - 173.2	Mud		10 Y 6/2	30.9	0	3472	27	2.14	25	1	
61	176.2 - 179.2	Pebbly sandy mud		10 Y 6/2	35.2	0	6374	34	2.32	45	2	
62	179.2 - 182.2	Pebbly sandy mud		10 Y 6/2	26.5	0	4285	35	2.05	35	0	
64	185.2 - 188.2	Pebbly muddy sand		10 R 6/2	26.1	0	2356	24	1.41	128	1	
66	190.7 - 193.7	Pebbly muddy sand		10 R 6/2	31.3	0	486	25	1.12	123	6	
67	193.7 - 196.7	Pebbly muddy sand		10 R 6/2	32.2	0	20	6		2	0	

[1] _Neogloboquadrina pachyderma_ (Ehrenberg) is the only species present.

[2] Colour determined using the Geological Society of America Rock-Color Chart.

[3] Diversities are listed for samples containing greater than 100 tests.

[4] X...Present

Table 9: Percent abundances of benthonic foraminifers ≥75 μm in samples fr

Species	20	21	22	23	24	26	Zone 5 28	29
Astrononion gallowayi Loeblich and Tappan		X[2]				1.37	2.02	1.48
Bolivina pseudopunctata Höglund								
Buccella arctica (Voloshinova)		X	X	9.56	X	2.74	0.58	0.33
Buccella calida (Cushman and Cole)		X						
Buccella frigida (Cushman)	X	X	X	18.35	X	15.75	11.53	9.70
Buliminella hensoni Lagoe								
Cassidulina reniforme Nørvang	X	X	X	1.55	X	1.37		0.99
Cassidulina teretis Tappan		X						
Cibicides lobatulus (Walker and Jacob)	X	X		1.29			0.86	1.64
Dentalina frobisherensis Loeblich and Tappan								
Dentalina sp.						0.68		
Elphidiella arctica (Parker and Jones)								
Elphidium bartletti Cushman								
Elphidium excavatum (Terquem) forma *clavata* Cushman	X	X	X	29.46	X	26.71	14.70	19.24
Elphidium subarcticum Cushman								
Elphidium sp. A								
Eoeponidella pulchella (Parker)				0.26			0.29	
Epistominella arctica Green								
Fissurina cucurbitasema Loeblich and Tappan								
Fissurina marginata (Montagu)					X			
Fissurina ventricosa (Wiesner)								
Fursenkoina loeblichi (Feyling-Hanssen)				0.78	X		0.29	0.16
Fursenkoina sp.								
Glandulina laevigata d'Orbigny								
Glandulinoides ittai (Loeblich and Tappan)								
Haynesina orbicularis (Brady)	X	X	X	5.17	X	9.59	3.46	4.11
Haynesina sp.	X			0.78				0.16
Islandiella helenae Feyling-Hanssen and Buzas	X	X	X	8.27	X	21.23	59.37	49.34
Islandiella islandica (Nørvang)		X						
Islandiella norcrossi (Cushman)			X	0.78		5.48	1.44	1.64
Lagena gracillima (Seguenza)								
Lagena laevis (Montagu)								
Lagena meridionalis Wiesner								
Lagena mollis Cushman				0.26				0.33
Lagena sp.								
Melonis zaandami (van Voorthuysen)								
Nonionellina labradorica (Dawson)		X		22.74	X	15.07	3.46	9.05
Oolina acuticostata (Reuss)								
Oolina caudigera (Wiesner)								
Oolina hexagona (Williamson)								
Oolina lineata (Williamson)								
Oolina melo d'Orbigny								
Oolina williamsoni (Alcock)								
Oolina sp.								
Patellina corrugata Williamson								
Pateoris hauerinoides (Rhumbler)								
[1]Polymorphinid								
Pseudoparrella takayanagii (Iwasa)	X		X	0.78			1.73	0.82
Stetsonia horvathi Green								
Trifarina hughesi (Galloway and Wissler)							0.29	0.99
Triloculina trihedra Loeblich and Tappan								
Number of species	8	12	8	14	9	10	13	15

[1]Includes species of the Family Polymorphinidae.

[2]X...Species present in sample containing less than 100 tests.

samples from Site 32.

Sample Number																	
Zone 5									Zone 4			Zone 3			Zone 2		
28	29	31	33	35	38	40	42	45	49	53	56	59	61	62	64	66	67
2.02	1.48	0.70	1.68	0.23		0.28		0.21	0.54	0.29	0.07	1.09	2.86	9.73	2.08	0.82	
										0.02	0.01						
0.58	0.33	4.20	3.36	0.68	1.54	0.37		0.63	0.76	0.61	1.45	2.36	3.94	1.59	0.42	0.62	
													0.03	0.09			
11.53	9.70	16.08	26.05	11.09	39.00	25.05	28.34	21.01	11.30	6.74	1.08	2.51	4.97	1.07		0.41	
											0.05	0.06	0.02	0.21	0.04	0.82	
	0.99	1.40	1.68	5.88	2.70	6.15	0.82	8.19	7.11	9.98	11.63	13.94	16.66	37.36	59.13	78.19	X
												0.06		0.02	0.21	0.21	
0.86	1.64	0.70	0.84	1.36	2.32	1.65	2.72	1.68	2.55	1.84	0.77	4.58	1.68	4.32	4.16	3.29	X
													0.03				
													0.02	0.02	0.08		X
							0.27		0.09	0.04	0.01	0.03	0.05	0.02			
14.70	19.24	27.27	34.45	60.18	32.05	44.68	41.42	36.97	64.67	64.23	30.96	12.59	16.25	7.56	5.01	4.94	X
		0.70										5.88	2.75	0.75	0.25	0.41	
									0.03		0.01		0.24	0.07			
0.29		0.70		0.68	0.39				0.06	0.10	0.64	0.84	1.19	1.35	0.04		
																1.03	
												0.03	0.02	0.16			
														0.02			
													0.02	0.16			
0.29	0.16			0.45		0.18			0.20	0.36	1.70	3.00	3.89	2.17	2.12	1.03	
											0.01		0.02	0.40	0.04	1.03	
												0.03					
															0.04		
3.46	4.11	8.39	14.29	0.45	4.25	3.12	1.63	1.05	0.23	0.38	0.15	0.03	0.36	0.14	0.13	0.21	
	0.16		1.68	0.45	0.77	0.73	0.27	1.47	0.26	0.19	0.17	2.10	1.87	0.72		0.62	
59.37	49.34	28.67	10.92	7.47	6.18	5.32	6.27	4.41	3.34	4.71	4.79	4.38	9.96	10.11	7.47	0.41	
														0.12	0.38	0.21	X
1.44	1.64	3.50		5.43	0.77	0.64	1.63	1.05	1.30	2.70	17.18	37.96	25.13	18.62	17.44	1.44	X
												0.03	0.06				
												0.29	0.11	0.07			
												0.03	0.03	0.05			
	0.33	0.70				0.18			0.09			0.03					
										0.02			0.02				
				0.23							0.01	1.93	2.32	1.19	0.21		
3.46	9.05	2.10	3.36	3.62	8.88	8.90	14.44	22.27	6.80	7.34	28.51	4.78	4.13	1.00	0.13	0.62	
														0.02			
														0.02	0.04		
													0.02				
														0.02			
												0.03		0.07			
													0.03	0.14	0.04	0.21	
											0.01		0.03				
						0.09											
																0.82	
						0.09				0.06	0.09		0.08	0.02		0.21	
1.73	0.82	2.10	1.68	1.81	1.16	2.57	2.18	1.05	0.68	0.38	0.65	1.27	1.18	0.59	0.25	0.62	
															0.13	0.62	
0.29	0.99	2.80										0.17	0.06			0.21	
										0.02	0.01				0.13	1.03	
13	15	15	11	15	12	16	11	12	17	19	23	27	34	35	24	25	6

species of Zones 2 to 5 are listed in Table 10.

Trends in the number of tests per gram of dry sediment, the number of species plus Polymorphinid and species diversity [H(S)] are recognized for the benthonic foraminiferal assemblages from Zones 2 to 5 (Fig. 8). The number of tests per gram of dry sediment increases from less than 1 at the base of Zone 2 to a maximum of 249 at the base of Zone 4 and then decreases to less than 35 in Zone 5. The number of species plus Polymorphinid increases from 6 at the base of Zone 2 to 35 at the base of Zone 3 and then decreases to $\leq$17 at the top of Zone 4 and in Zone 5. The mean value of benthonic foraminifer species diversity [H(S)] increases from 1.27 in Zone 2 to 2.17 in Zone 3 and decreases to 1.47 in Zone 4. The mean species diversity for Zone 5 (1.69) is higher than those for Zone 2 and 4 and lower than that for Zone 3.

The planktonic foraminifer <u>Neogloboquadrina pachyderma</u> is absent in Zones 1 and 6. The number of planktonic foraminiferal tests is highest (greater than 4 tests per gram of dry sediment) in Zone 2 and lowest (less than 1 test per gram of dry sediment) in Zone 5. Diatoms occur from the middle part of Zone 4 to the top of Zone 6 and are most abundant in the latter zone (Fig. 9). Gypsum is only present in Zones 5 and 6.

Table 10: Range and mean percent abundances of characteristic benthonic foraminiferal species at Site 32 in residues ≥ 75 µm.

Species	Abundance (%)											
	Zone 2			Zone 3			Zone 4			Zone 5		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Cassidulina reniforme Nørvang	59.13	78.19	68.66	13.94	37.36	22.65	7.11	11.63	9.57	0.82	8.19	2.79
Islandiella norcrossi (Cushman)	1.44	17.44	9.44	18.62	37.96	27.24	1.30	17.18	7.06	0.64	5.48	2.03
Elphidium excavatum (Terquem) forma *clavata* Cushman	4.94	5.01	4.98	7.56	16.25	12.13	30.96	64.67	53.29	14.70	60.18	33.38
Nonionellina labradorica (Dawson)	0.13	0.62	0.38	1.00	4.78	3.30	6.80	28.51	14.22	2.10	22.27	10.35
Buccella frigida (Cushman)	0.00	0.41	0.21	1.07	4.97	2.85	1.08	11.30	6.37	9.70	39.00	20.18
Islandiella helenae Feyling-Hanssen and Buzas	0.41	7.47	3.94	4.38	10.11	8.15	3.34	4.79	4.28	4.41	59.37	18.86
[1] Number of samples		2			3			3			11	

[1] Only samples containing greater than 100 tests were used to calculate mean percent abundances.

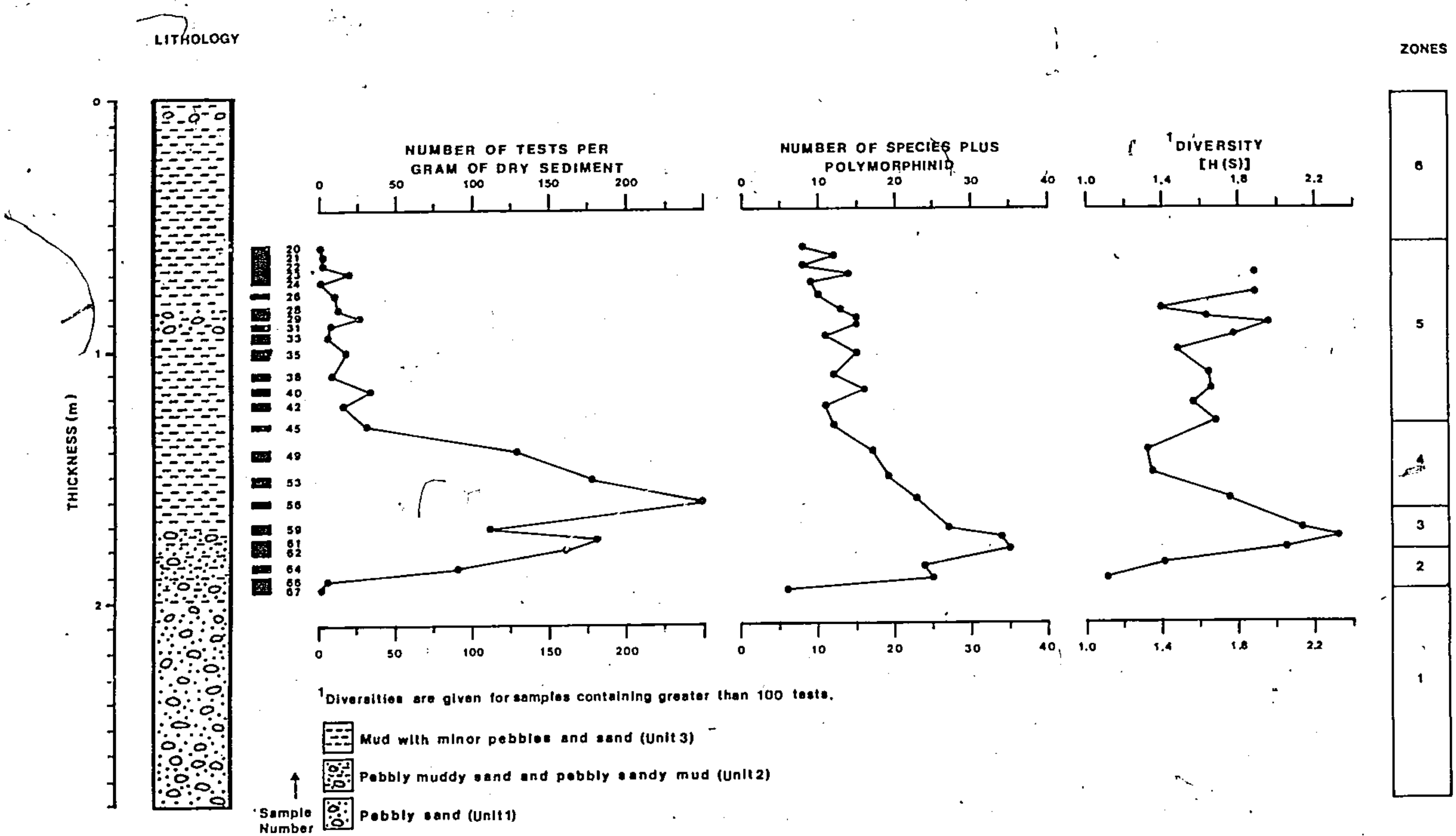

Figure 8: Benthonic foraminiferal data for samples from Site 32 based on residues ≥ 75 µm.

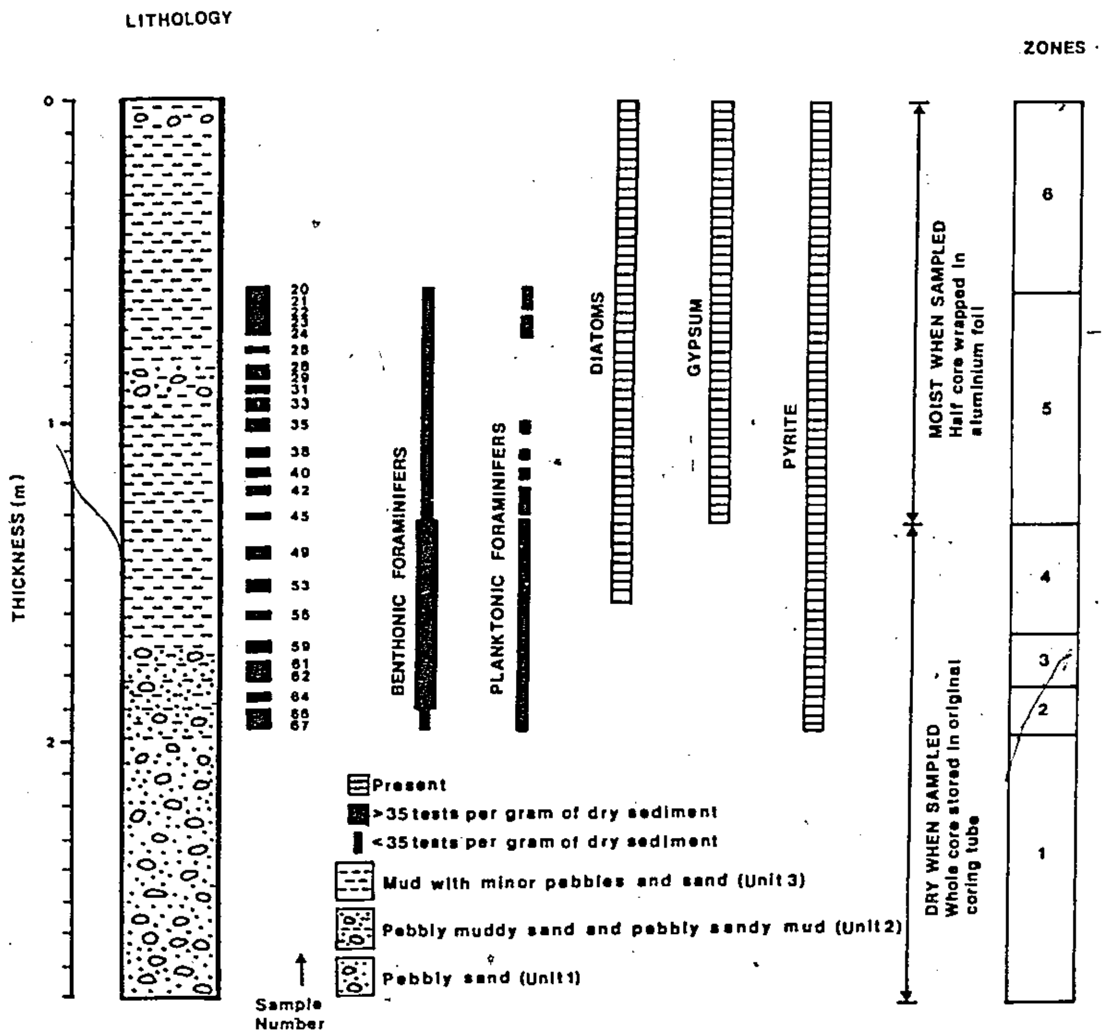

Figure 9: Distribution of foraminifers, diatoms, gypsum and pyrite in section from Site 32. Foraminiferal data based on residues $\geq$75 µm.

SIGNIFICANCE OF GYPSUM IN SAMPLES FROM SITE 32

There are reports of authigenic gypsum in marine sediments. Siesser and Rogers (1976) described authigenic gypsum and pyrite in Upper Miocene-Lower Pliocene silty clays from the continental slope off South West Africa. Briskin and Schreiber (1978) reported gypsum crystals growing around planktonic foraminiferal tests in Pleistocene sediments from the Rio Grande Rise. They postulated that a reaction between calcium dissolved from calcareous microfossils and sulphate from overlying waters produces gypsum in marine sediments.

Schnitker _et al_. (1980) reported that the abundance of calcareous foraminifers was not consistent in samples from cored sections which had dried out over a period of two to three years. They pointed out that barren intervals occurred adjacent to intervals containing large numbers of calcareous tests and that subsamples of the supposedly barren intervals contained large numbers of foraminiferal tests. Gypsum crystals were present in the samples which were dry, and absent in samples, which had not dried out over the two-to three-year period. They reasoned that gypsum formed as a result of dissolution of calcareous foraminifers during storage.

Schnitker _et al_. (_op_. _cit_.) tested their hypothesis using two short sediment cores from Johns Bay and Clark's Cove, Maine. Triplicate samples were obtained from different levels in the cores for chemical and microfaunal analyses.

One set of samples was used to determine the acid-volatile sulphide content. The second set of samples was washed immediately and the foraminifers in the residues were identified and counted. The third set of samples were placed in plastic containers and allowed to dry at room temperature for three months.

The acid-volatile sulphur content of the samples ranged from 14.5 to 171 ppm. A comparison of the foraminiferal assemblages from the samples which were washed immediately and those from samples which were dried for three months revealed a 35 to 69% loss of tests in the dried samples. The foraminiferal tests from residues of the samples which were washed immediately retained their original glossy shine, whereas the tests from the residues of the dried samples had lost their shine and the surface of some of the tests were pitted and frosted. Furthermore, gypsum crystals were present in all of the dried samples and absent in the samples which were washed immediately. Thus, they concluded that gypsum forms in marine sediments containing sulphide and calcareous foraminifers when the sediments are dried in the presence of oxygen as follows:

1. $4FeS + 9O_2 + 6H_2O = 4FeO(OH) + 4SO_4^{2-} + 8H^+$

   or

   $2FeS_2 + 7\frac{1}{2}O_2 + 5H_2O = 2FeO(OH) + 4SO_4^{2-} + 8H^+$

   Oxidation of sulphides (FeS or FeS_2) releases dissolved sulphate and lowers the pH of the interstitial water.

2. $H^+ + CaCO_3 = Ca^{2+} + HCO_3^-$

   Calcareous foraminifers dissolve in the acid interstitial water releasing calcium and bicarbonate.

3. $Ca^{2+} + SO_4^{2-} + 2H_2O = CaSO_4 2H_2O$

   The increase in calcium and sulphate in the interstitial fluid during desiccation results in supersaturation and precipitation of gypsum.

The cored section from Site 32 was stored at room temperature at the Ottawa Office of the Geological Survey of Canada. Pyrite is present in the marine portion of the section (0 - 196.7 cm) and gypsum crystals are present from 0 - 131.7 cm (Fig. 9). The lower part of the gypsum-bearing interval (59.0 - 131.7 cm) contains calcareous foraminifers. The foraminiferal tests were not whole and their surfaces are opaque, pitted and etched. The foraminifers in the samples below the gypsiferous interval retained their surface shine, i.e., they do not appear to have been affected by dissolution. Also, the number of foraminiferal tests per gram of dry sediment for the samples from the lower part of the gypsum-bearing interval is significantly lower (<35) than that for samples directly below the base of the interval (>120). The presence of gypsum in the upper part of the cored section from Site 32 is best explained by the process described by Schnitker et al. (1980).

The gypsum-bearing interval was split in half along its length and cut into five segments which were wrapped in aluminium foil. Each segment was partially dried out when sampled for this study. The segments were exposed to the atmosphere for less than one hour while they were cut into roughly 3 cm intervals for microfaunal analysis. The segments were exposed to the atmosphere while they were split into half. The duration of exposure to the atmosphere is unknown. However, it appears to have been sufficient to convert the sulphide on the exterior of the segments to sulphate and to lower the pH of the interstitial water. The acid interstitial water dissolved the calcareous foraminifers which were present and produced calcium and bicarbonate ions. Desiccation of the segments resulted in increased calcium and sulphate concentrations and the precipitation of gypsum while the segments were exposed to the atmosphere and/or during storage. The foraminiferal tests in the interval 0 - 59.0 cm were completely dissolved, whereas, some of the tests between 59.0 and 131.7 cm were only partially dissolved by the acid interstitial waters. The larger thicker-walled species, Buccella frigida and Islandiella helenae, which are present in the lower part of the gypsum-bearing interval appear to be resistant to dissolution.

The lower part of the cored section from Site 32 (131.7 - 280.2 cm) was stored in the original coring tube and was cut into two segments which were sealed at both ends. Calcareous foraminifers and pyrite are present in the marine portion of the section in the coring tubes (131.7 - 196.7 cm). The foraminifers retained their surface shine and do not appear to have been affected by dissolution. The seals at the ends of the segments were not air-tight because the sediments in the tubes were dry. During storage air was in contact with the exterior of the cored section in the tube. Moisture moved from the interior to the exterior of the section and was removed by air which passed through the seals. The amount of oxygen in contact with the exterior of the sediment was not sufficient to oxidize any pyrite that was present at the sediment-air interface. Therefore, gypsum is not present between 131.7 and 196.7 cm in the section although the interval had dried out. Gypsum is also not present in the cored section from Site 31 which contained calcareous foraminifers and pyrite and was dry when sampled. The section was not split along its length; it was cut into three segments and stored in the original coring tube with seals at the ends of the segments.

VARIATION IN SPECIES PROPORTIONS (SITE 31)

The range and mean percent abundances of the characteristic benthonic foraminiferal species for residues ≥ 75 µm and ≥ 150 µm at Site 31 are presented in Table 4. The characteristic species in order of decreasing mean abundance in the ≥ 75 µm residues are *Cassidulina reniforme*, *Elphidium excavatum* forma *clavata*, *Cibicides lobatulus*, *Cassidulina teretis* and *Islandiella norcrossi* (Fig. 4). *Cibicides lobatulus*, *Elphidium excavatum* forma *clavata*, *Islandiella norcrossi*, *Cassidulina teretis*, *Cassidulina reniforme* and

Islandiella helenae are the characteristic species in decreasing order of mean abundance in the ≥150 μm residues (Fig. 6). The smaller Cassidulina reniforme is more abundant in residues ≥75 μm and the larger Cibicides lobatulus, Islandiella helenae and Islandiella norcrossi are more abundant in residues ≥150 μm (Table 4). Elphidium excavatum forma clavata and Cassidulina teretis have similar mean abundances in residues ≥75 μm and ≥150 μm. Benthonic foraminiferal assemblages based on residues ≥150 μm are characterized by the larger but not necessarily the most abundant species.

The number of tests of benthonic and planktonic foraminifers, the number of benthonic foraminiferal species and the benthonic foraminiferal diversity for each sample based on both the ≥75 μm and ≥150 μm residues are presented in Table 11. Plots of the number of tests per gram of dry sediment, the number of species plus Polymorphinid and species diversities for benthonic foraminiferal assemblages based on residues ≥75 μm and ≥150 μm are shown in Figure 10. The number of tests per gram of dry sediment is greater in residues ≥75 μm (34 to 467) compared to residues ≥150 μm (9 to 161). Similarily, the number of species plus Polymorphinid is greater in residues ≥75 μm (26 to 57) compared to residues ≥150 μm (19 to 43). Species diversity ranges from 1.86 to 2.19 in residues ≥75 μm and 1.89 to 2.33 in residues ≥150 μm. The planktonic foraminifer Neogloboquadrina pachyderma is more abundant in residues ≥75 μm (Table 11).

Table 11: Foraminiferal data for samples from Site 31 based on residues ≥ 75 µm and ≥ 150 µm.

Sample Number	Residue ≥75 µm: Benthonic: Number of Tests: Agglutinated	Residue ≥75 µm: Benthonic: Number of Tests: Calcareous	Residue ≥75 µm: Benthonic: Number of Species (S)	Residue ≥75 µm: Benthonic: Diversity [H(S)]	Residue ≥75 µm: Planktonic[1]: Number of Tests: Sinistral	Residue ≥75 µm: Planktonic[1]: Number of Tests: Dextral	Residue ≥150 µm: Benthonic: Number of Tests: Agglutinated	Residue ≥150 µm: Benthonic: Number of Tests: Calcareous	Residue ≥150 µm: Benthonic: Number of Species (S)	Residue ≥150 µm: Benthonic: Diversity [H(S)]	Residue ≥150 µm: Planktonic[1]: Number of Tests: Sinistral	Residue ≥150 µm: Planktonic[1]: Number of Tests: Dextral
1	314	18674	57	2.13	2331	72	70	6477	43	2.05	1217	33
5	2	4379	37	2.09	314	11	1	1706	28	2.10	177	6
10	0	5064	36	2.10	297	11	0	1622	26	2.14	136	7
16	0	1927	33	2.10	99	4	0	615	25	2.07	56	3
22	8	3955	39	2.15	187	7	0	1187	26	2.21	107	4
28	0	1105	29	2.07	74	6	0	309	20	2.26	36	2
34	0	1144	26	2.09	110	6	0	341	21	2.15	37	4
40	0	5852	41	1.86	619	23	0	1326	30	2.25	223	6
45	0	1424	35	2.19	115	5	0	313	24	2.20	46	2
51	0	2372	34	2.01	315	12	0	656	22	2.16	159	6
57	0	2234	32	2.03	242	7	0	575	23	2.20	108	3
63	0	3417	32	1.88	479	23	0	937	22	1.89	262	12
69	0	1050	33	2.02	68	1	0	315	25	2.33	24	0
75	0	1241	26	1.93	142	3	0	303	19	2.25	48	1
81	0	4325	37	2.12	517	15	0	982	27	2.14	187	5
82	0	4358	35	2.05	436	13	0	1324	26	2.22	225	7

[1] *Neogloboquadrina pachyderma* (Ehrenberg) is the only species present.

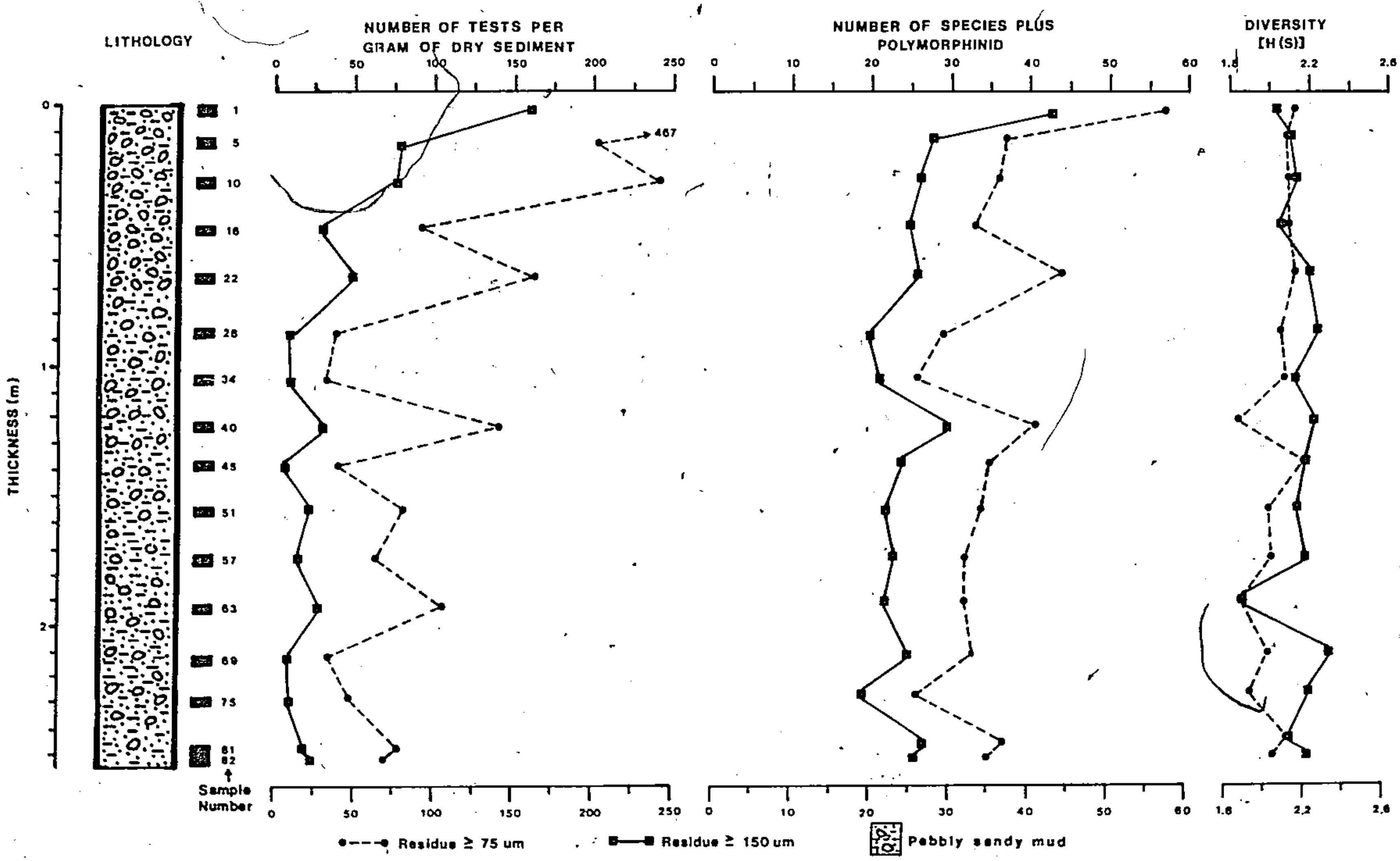

Figure 10: Benthonic foraminiferal data for samples from Site 31 based on residues ≥75 μm and ≥150 μm.

The differences in the benthonic foraminiferal assemblages from Site 31 based on the ≥ 75 µm and ≥ 150 µm fractions are similar to those described by Schröder *et al*. (1987) and Sen Gupta *et al*. (1987). Schröder *et al*. (*op*. *cit*.) compared the abundance and distribution of benthonic foraminiferal species in assemblages from the >63 µm and >125 µm fractions. They reported that there is a significant loss of smaller-sized tests, including environmental indicator species, in assemblages from the coarser 125 µm fraction. They recommended that the sieve size used in foraminiferal studies should be standardized and that the 63 µm lower limit should be chosen instead of the coarser fractions (>125 µm). Sen Gupta *et al*. (*op*. *cit*.) also pointed out that a significant amount of information is lost when assemblage data from coarse sieve fractions are used in studies of deep sea benthonic foraminifers.

LATE QUATERNARY LITHOLOGIC UNITS

Kravitz (1982) pointed out that a single, unfossiliferous unit, the Ellesmere Island Till (Till 1), is present in western Kane Basin off the coast of Ellesmere Island (Fig. 3). The cored section from Site 31 was obtained 32 km east of Bache Peninsula in the area where Kravitz (1982) reported Ellesmere Island Till (Till 1) in cored sections and surficial sediment samples. The presence of large numbers of foraminiferal tests and shell fragments in the cored section from Site 31 suggests that the pebbly, sandy mud in the section represents a lithologic unit which was not recognized by Kravitz (1982).

Site 31 is located along the main channel joining the Arctic Ocean to Baffin Bay. Therefore, it seems likely that the pebbly, sandy mud in the cored section from Site 31 may consist of ice-rafted materials.

Kravitz (1982) recognized a lithologic succession from the Greenland Till (Till 2) in the lower part to water-transported sediments in the upper part of cored sections in eastern Kane Basin adjacent to Inglefield Land (Fig. 3). The Greenland Till (Till 2) is unfossiliferous and poorly sorted, whereas the fine-grained, water-transported sediments are characterized by crude bedding, thin laminae and the presence of shell fragments (Table 1). A similar lithologic succession was recognized in the cored section from Site 32. The unfossiliferous, pale red, pebbly sand (Unit 1) in the lower part of the section may be equivalent to the Greenland Till (Till 2). Unit 2 contains fossils and represents a transition from the pale red, pebbly sand (Unit 1) in the lower part to the pale olive to light olive gray, massive mud (Unit 3) in the upper part of the section. Unit 3 contains diatoms, shell fragments and foraminiferal tests and is similar to the water-transported sediments described by Kravitz (1982).

MODERN DISTRIBUTION OF CHARACTERISTIC FORAMINIFERS

Paleoceanographic interpretation of Late Quaternary fossil assemblages are based on an understanding of the environmental conditions controlling the distribution of extant species which are present in the fossil assemblages. The modern distribution of the characteristic benthonic foraminiferal species and the planktonic foraminifer, *Neogloboquadrina pachyderma*, are used to interpret the physical and chemical conditions of the bottom waters and the surface waters during deposition of the sediments at Sites 31 and 32.

The characteristic benthonic foraminiferal species in the cored sections are *Buccella frigida*, *Cassidulina reniforme*, *Cassidulina teretis*, *Cibicides lobatulus*, *Elphidium excavatum* forma *clavata*, *Islandiella helenae*, *Islandiella norcrossi* and *Nonionellina labradorica*. The modern distribution of the species are summarized in Table 12.

Planktonic foraminifers generally live in the upper layers of offshore waters away from terrestrial influence and are most abundant in areas of upwelling and mixing. The number of planktonic foraminifers living in the surface waters is controlled by the surface water temperature, salinity and amount of ice cover. The number of planktonic foraminifers preserved in bottom sediments is a function of the number of planktonic foraminifers in the surface waters, sedimentation rate, post-mortem dissolution of tests and predation. If the sedimentation rate is constant and dissolution and predation is negligible, then the number of planktonic foraminifers should be related to the surface

Table 12: Modern distribution of characteristic benthonic foraminiferal species at Sites 31 and 32.

Species	Reference	Location	Temperature (°C)	Salinity (‰)	Depth (m)	Abundance (%)
<u>Buccella frigida</u> (Cushman)	Leslie (1965)	Hudson Bay	-1.78 to 2.98	29.34 to 33.39	26 to 230	
<u>Cassidulina reniforme</u> Nørvang	[1]Elverhøi <u>et al</u>. (1980)	Kongsfjorden, Spitsbergen	~2	~33.0	48 to 58	6.0 to 83.4
	Vilks <u>et al</u>. (1982)	Lake Melville Labrador Shelf	-0.5 -1 to 2	28.0 ~33 to 34	100 to >200 70 to 370	5 to 30 5 to 25
<u>Cassidulina teretis</u> Tappan	Lagoe (1979)	Arctic Ocean	0 to 3	34.9 to 35.1	350 to 900	10 to 30
<u>Cibicides lobatulus</u> (Walker and Jacob)	Sen Gupta (1971)	Tail of the Grand Banks	-0.9 to 3.7	33±1	46 to 110	23.8 to 52.8
	Rodrigues and Hooper (1982a)	Gulf of St. Lawrence	-2.0 to 2.0	30.7 to 33.6	55 to 142	Average abundance in Association 1 = 48.8%
	Vilks <u>et al</u>. (1982)	Labrador Shelf	-1.5 to 2.0	~33 to 34	100 to 370	<10
<u>Elphidium excavatum</u> (Terquem) forma <u>clavata</u> Cushman	[2]Vilks <u>et al</u>. (1979)	Beaufort Shelf	1 to 2	30 to 32	<75	>40
	Vilks <u>et al</u>. (1982)	Labrador Shelf	-1.5 to 2.0	~33 to 34	100 to 370	5-40
	[2]Rodrigues and Hooper (1982a,b)	Gulf of St. Lawrence	-2 to 12 4.1 to 4.9	<32 34.5 to 34.9	18 to 50 270 to 520	6 to 20* 2.1 to 28
<u>Islandiella helenae</u> Feyling-Hanssen and Buzas	Vilks <u>et al</u>. (1982)	Labrador Shelf Lake Melville	-1.5 to 2.0 -0.5	~33 to 34 28	100 to 370 ~150	5 to 50 5%
	Rodrigues and Hooper (1982a)	Gulf of St. Lawrence	-2.0 to 2.3	31.4 to 33.6	73 to 142	Average abundance in Association 2 = 42.5%
<u>Islandiella norcrossi</u> (Cushman)	Leslie (1965)	Hudson Bay	-1.56 to -1.11	30.85 to 33.31	35 to 230	<5
<u>Nonionellina labradorica</u> (Dawson)	Vilks (1969)	Hecla and Griper Bay and Hazen Strait	0 to 3	34.9 to 35.1	200 to 300	<0.5
	Sen Gupta (1971)	Tail of the Grand Banks	2.1 to 8.2	33±1	73 to 91	0.7 to 1.7
	Williamson (1982)	Nova Scotian Shelf	>3	>34		
	Vilks <u>et al</u>. (1982)	Labrador Shelf	>2	>34	>300	15 to 40
	[3]Rodrigues and Hooper (1982a)	Gulf of St. Lawrence	>4	>34	>200	Average abundances in Associations 5, 7, 8 are 6.9, 5.7 and 8.1% respectively

[1]Identified as <u>Cassidulina crassa</u>.

[2]Identified as <u>Elphidium clavatum</u>.

[3]Identified as <u>Nonionella labradorica</u>.

*Visual estimate.

water temperature and salinity and to open-water conditions (*i.e.*, absence of ice). However, if sedimentation is episodic, variations in the abundance of planktonic foraminifers in the sediment may simply reflect the variation in sedimentation rate.

Bé and Tolderlund (1971) reported that *Globigerina pachyderma* (=*Neogloboquadrina pachyderma*) is the only planktonic foraminifer in the Arctic Ocean and the most abundant species in waters north of the Arctic Circle, in the Labrador Sea and in Antarctic waters where surface water temperatures are between 0 and 9°C. Sinistrally coiled tests are usually greater than 90% of the planktonic foraminiferal population in waters between 0 and 4°C.

Vilks (1974) concluded that during cold periods continuous pack ice cover leads to smaller-sized planktonic foraminiferal populations. Jansen *et al.* (1983) pointed out that the presence of a low-salinity layer produced by glacial meltwater may result in low numbers of planktonic foraminifers in the surface waters.

Vilks (1975) compared planktonic foraminiferal assemblages collected in net tows to assemblages in bottom sediments from the Beaufort Sea and Northwest Passage of the Canadian Arctic Archipelago. He concluded that an average loss of 80% of the planktonic fauna occurs as a result of solution and predation. Stehman (1972) described the distribution of the planktonic foraminifers *Globigerina pachyderma* (=*Neogloboquadrina pachyderma*) and *Globigerina* bu[illegible]oides d'Orbigny in the bottom sediments and water columns of Baffin Bay, Davis Strait and the Labrador Sea. *Neogloboquadrina pachyderma* is the only planktonic foraminifer north of Davis Strait (Fig. 1). Stehman (*op. cit.*) reported that the number of tests preserved in the sediments does not accurately reflect the number of tests living in the overlying waters and that significant numbers of planktonic foraminifers living in the water column do not reach the seafloor.

PALEOCEANOGRAPHY

Site 31

The characteristic benthonic foraminiferal species in the cored section from Site 31 are *Cassidulina reniforme*, *Elphidium excavatum* forma *clavata*, *Cibicides lobatulus*, *Cassidulina teretis* and *Islandiella norcrossi* (Fig. 4). The presence of *Cassidulina reniforme* and *Elphidium excavatum* forma *clavata* is indicative of bottom-water temperatures between -1 and 2°C and salinities ranging from 28 to 33‰ (Table 12).

Cibicides lobatulus has been reported in bottom sediment samples (sands and gravelly sands) from the Labrador Shelf, Tail of the Grand Banks and Gulf of St. Lawrence where bottom-water temperatures are between -2 and 3.7°C and salinities greater than 30.7‰ (Table 12). The temperature and salinity ranges for *Cibicides lobatulus* from these three regions are similar to the temperature and salinity conditions postulated above for the bottom waters at Site 31 (*i.e.*, temperature -1 to 2°C, salinity 28 to 33‰) based on the abundances of *Cassidulina reniforme* and *Elphidium excavatum* forma *clavata*.

Cassidulina teretis represents 10 to 30% of the benthonic foraminiferal fauna at depths between 350 and 900 m in the Arctic Ocean (Table 12). Bottom-water temperatures (-1 to 2°C) at Site 31 during the Late Quaternary were similar to present day bottom-water temperatures (0 to 3°C) at depths ranging from 350 to 900 m in the Arctic Ocean. However, bottom-water salinities were lower (≤ 33‰) at Site 31 during the Late Quaternary compared to the present day bottom-water salinities (34.9‰ to 35.1‰) between 350 and 900 m in the Arctic Ocean. Therefore, the low abundance (2.78 to 12.06%; Table 4) of *Cassidulina teretis* in benthonic foraminiferal assemblages from Site 31 compared to the present abundance (10 to 30%) of *Cassidulina teretis* in the Arctic Ocean at depths between 350 and 900 m is related to lower-salinity bottom waters (≤ 33‰) at Site 31 during the Late Quaternary.

The environmental factors controlling the distribution of *Islandiella norcrossi* are not well documented. However, the occurrence of *Islandiella norcrossi* in low abundances (4.16 to 9.72%; Table 4) in benthonic foraminiferal assemblages at Site 31 suggests that the species is present in areas characterized by cold bottom-water temperatures (-1 to 2°C) and salinities ranging from 28 to 33‰.

The planktonic foraminifer, Neogloboquadrina pachyderma, is present in all samples from the cored section at Site 31 (Table 2) and 96.7% of the tests are sinistrally coiled. The large number of planktonic foraminifers and the dominance of sinistrally coiled tests suggest that Site 31 was not permanently ice-covered and that surface-water temperatures were between 0 and 4°C during deposition of the sediments at Site 31.

Site 32

The characteristic benthonic foraminiferal species in the cored section from Site 32 are Cassidulina reniforme, Islandiella norcrossi, Elphidium excavatum forma clavata, Nonionellina labradorica, Buccella frigida and Islandiella helenae (Fig. 7). Six zones are recognized on the basis of the distribution and abundance of the characteristic species.

The stratigraphically oldest zone (No. 1, Fig. 7) is characterized by the absence of foraminifers. The pale red, pebbly sand (Unit 1) in Zone 1 (Fig. 7) is considered to be a glacial deposit.

Cassidulina reniforme is the most abundant benthonic foraminiferal species in Zone 2 (Fig. 7) and is indicative of cold bottom waters (-1 to 2°C) and salinities ranging from 28 to 33‰ (Table 12). Elverhøi et al. (1980) described similar benthonic foraminiferal assemblages dominated by Cassidulina crassa (=Cassidulina reniforme) in core top samples from Kongsfjorden, Spitsbergen.

Elverhøi et al. (op. cit.) pointed out that Cassidulina crassa represented 6 to 83.4% of the benthonic foraminiferal assemblages where bottom-water temperatures were approximately 2°C and salinities were about 33‰ in the fjord adjacent to the Kongsvegen glacier.

The most abundant benthonic foraminiferal species in Zone 3 are Islandiella norcrossi and Cassidulina reniforme (Fig. 7). The higher mean percent abundance of Islandiella norcrossi in Zone 3 (27.24%; Table 10) compared to Zone 2 (9.44%) and the corresponding lower mean percent abundance of Cassidulina reniforme in Zone 3 (22.65%) relative to Zone 2 (68.66%) is related to changing bottom-water conditions at Site 32. The increase in abundance of Islandiella norcrossi in Zone 3 may be related to an increase in bottom-water temperature to greater than 2°C and/or an increase in bottom-water salinity to greater than 33‰. The changes in temperature and/or salinity explain the decrease in abundance of Cassidulina reniforme which prefers bottom-water temperatures ≤2°C and salinities between 28 and 33‰. Leslie (1965) reported that Islandiella norcrossi is present only in small numbers in Hudson Bay at depths ranging from 35 to 230 m where bottom-water temperatures are between -1.56 and -1.11°C and salinity ranges from 30.85 to 33.31‰ (Table 12). The low numbers of Islandiella norcrossi suggest that the species prefers bottom-water conditions different than the present temperature and salinity conditions in Hudson Bay.

Elphidium excavatum forma *clavata* and *Nonionellina labradorica* are the most abundant benthonic foraminiferal species in Zone 4 (Fig. 7). The mean percent abundance of *Elphidium excavatum* forma *clavata* increases from 12.13% in Zone 3 to 53.29% in Zone 4 (Table 10). Similarly, the mean percent abundance of *Nonionellina labradorica* increases from 3.30% in Zone 3 to 14.22% in Zone 4. Assemblages containing large numbers of *Elphidium excavatum* forma *clavata* from a water depth comparable to that at Site 32 (377 m) have been reported from the Labrador Shelf and the Gulf of St. Lawrence (Table 12). Temperatures range from -1.5 to 4.9°C on the Labrador Shelf and in the Gulf of St. Lawrence in areas where *Elphidium excavatum* forma *clavata* is abundant. Salinities on the Labrador Shelf and in the Gulf of St. Lawrence range from about 33‰ to 34.9‰. *Nonionellina labradorica* is most abundant in regions where bottom-water temperatures are greater than 2°C and salinities are greater than 34‰. Therefore, bottom-water temperatures of approximately 0 to 4°C and salinities greater than 34% are proposed for Zone 4.

In Zone 5 gypsum crystals are present and foraminiferal tests appear to have been affected by dissolution. The most abundant benthonic foraminiferal species are *Elphidium excavatum* forma *clavata*, *Buccella frigida*, *Islandiella helenae* and *Nonionellina labradorica* (Fig. 7). The larger, thicker-walled species, *Buccella frigida* and *Islandiella helenae* appear to be resistant to dissolution. The high mean percent abundances of Elphidium excavatum forma clavata (33.38%) and Nonionellina labradorica (10.35%) are suggestive of bottom-water temperatures between 0 and 4°C and salinities greater than 34‰ for Zone 5.

Gypsum crystals are present and foraminifers are absent in Zone 6. Oxidation of sulphides (e.g., FeS_2) in the sediment released dissolved sulphate and lowered the pH of the interstitial water. Calcareous tests dissolved in the acid interstitial water. Desiccation of the sediment during storage resulted in increased concentrations of calcium and sulphate and precipitation of gypsum.

The planktonic foraminifer, Neogloboquadrina pachyderma, is present in Zones 2 to 5 (Fig. 9). The number of planktonic foraminiferal tests is highest (greater than 4 tests per gram of dry sediment) in Zone 2 and lowest (less than 1 test per gram of dry sediment) in Zone 5 (Table 8). The presence of low numbers of planktonic tests in Zone 5 is related to the dissolution of calcareous tests during storage. The presence of predominantly sinistrally coiled tests (>95%) in Zones 2 to 5 suggests that Site 32 was not permanently ice-covered and that surface-water temperatures were between 0 and 4°C during deposition of the sediments between 59.0 and 196.7 cm in the cored section from Site 32.

The number of planktonic foraminiferal tests is greater in samples from Site 31 (Table 2) compared to the number of tests in samples from Site 32 (Table 8). The greater number of planktonic tests at Site 31 is related to the location of the site in western Kane Basin along the main channel joining the Arctic Ocean to Baffin Bay. The lower number of planktonic tests at Site 32 may be related to the proximity of the site to the Humboldt Glacier and glacial meltwater.

RADIOCARBON DATES

Blake (1977, 1987) concluded that the Greenland Ice Sheet and Ellesmere Island ice cap were contiguous and that the ice flowed southward from Kane Basin through Smith Sound into Baffin Bay during the last glaciation. Blake (1986) pointed out that the postglacial marine incursion into the Smith Sound-Kane Basin coastal region occurred approximately 9000 radiocarbon years BP on the basis of radiocarbon dates on pelecypod shells from raised marine deposits.

The radiocarbon date of 9170 ± 130 years BP (TO-771) from the lower part of the cored section at Site 31 (Fig. 11) is older than the previously reported dates on marine shells from east-central Ellesmere Island. The date suggests that Site 31 was ice-free earlier than the adjacent Smith Sound-Kane Basin coastal regions during the final retreat of the ice from the area.

A radiocarbon date of 3310 ± 70 years BP (TO-567) was obtained on a pelecypod valve from the upper part of the section at Site 31 (Fig. 11). The pelecypod valve may be

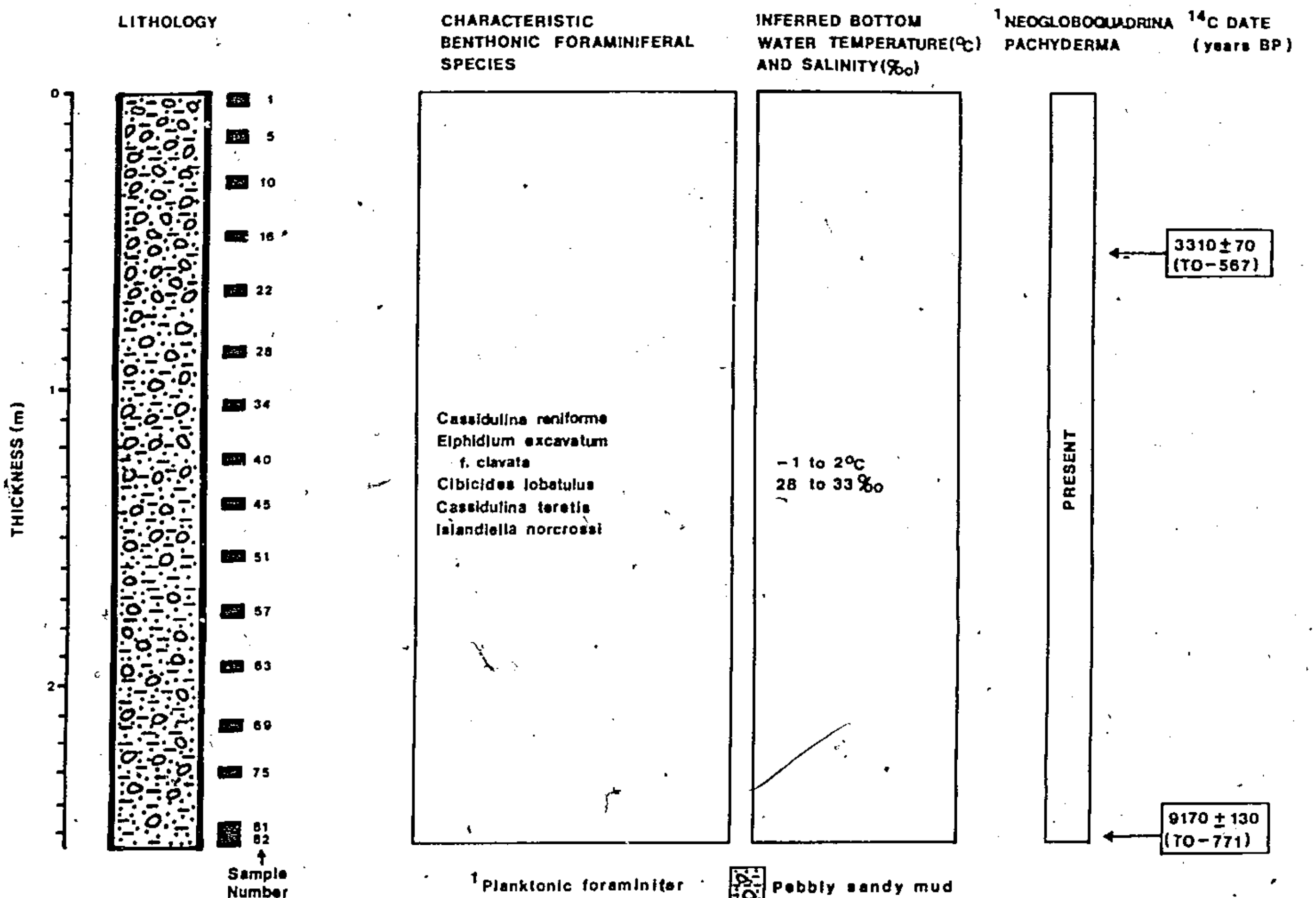

Figure 11: Summary of chronology, foraminiferal fauna and paleoenvironmental interpretation for section from Site 31.

reworked, therefore, 3310 ± 70 years BP represents a maximum age for the enclosing sediment.

A radiocarbon date of 7590 ± 120 years BP (TO-770) was obtained on benthonic foraminifers from the lower part of the section at Site 32 (Fig. 12). The presence of marine sediments below the dated level suggests that Site 32 was ice-free before circa 7600 radiocarbon years BP. The oldest date on marine shells from Inglefield Land which postdates the last glacial retreat is 7800 + 200 years BP (L-1091E; Nichols, 1969). The dates of 7590 ± 120 years BP (TO-770) and 7800 ± 200 years BP (L-1091E) overlap and suggest that Inglefield Land and Site 32 were deglaciated before circa 7600 radiocarbon years BP. Additional radiocarbon dates are required to correlate the chronology of events in Kane Basin with that on the adjacent landmasses.

SUMMARY AND CONCLUSIONS

The cored section from Site 31 in western Kane Basin consists of fossiliferous, pebbly, sandy mud (Fig. 11). Three lithologic units are recognized at Site 32 in eastern Kane Basin (Fig. 12). Unit 1, in the lower part of the section, is an unfossiliferous, pebbly sand. Unit 3, in the upper part of the section is a fossiliferous, massive mud. Unit 2 contains fossils and represents a transition from Unit 1 to Unit 3. The length of the cored sections at Sites 31 and 32 are 253.7 and 280.2 cm, respectively.

Seventy-five calcareous benthonic foraminiferal species

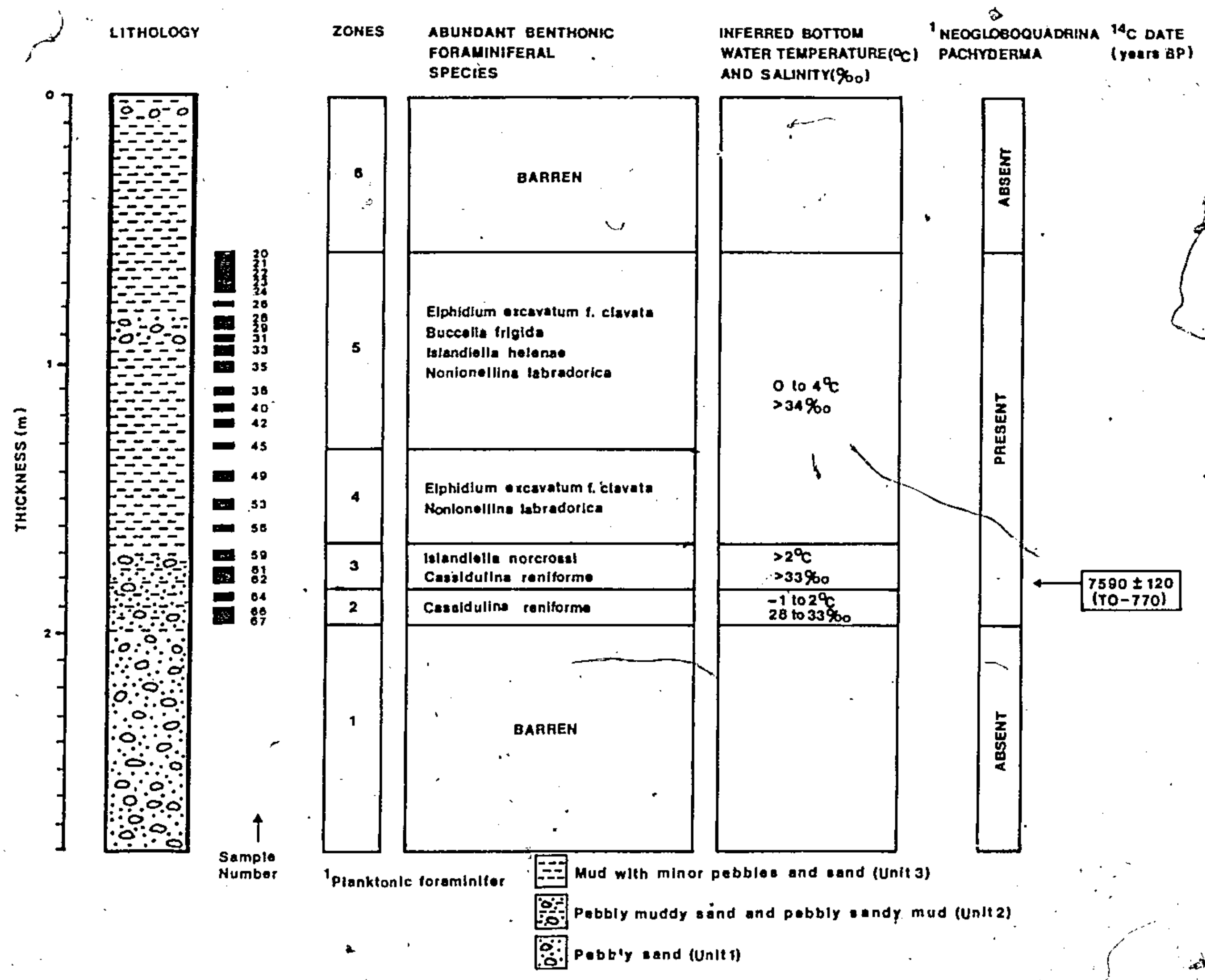

Figure 12: Summary of chronology, foraminiferal fauna and paleoenvironmental interpretation for section from Site 32.

excluding Polymorphinid and 9 agglutinated benthonic foraminiferal species were identified and 100 255 tests were counted in 40 samples from the two cored sections. A total of 7021 tests of the planktonic foraminifer Neogloboquadrina pachyderma were counted in 33 samples.

Benthonic foraminiferal assemblages at Site 31 based on residues ≥75 µm are characterized by Cassidulina reniforme, Elphidium excavatum forma clavata, Cibicides lobatulus, Cassidulina teretis and Islandiella norcrossi (Fig. 11). The benthonic foraminiferal assemblages suggest that bottom-water temperatures and salinities at Site 31 ranged from -1 to 2°C and 28 to 33‰, respectively, during the Late Quaternary.

Six zones are recognized for the cored section from Site 32 on the basis of the distribution and abundance of benthonic foraminifers (Fig. 12). The stratigraphically oldest zone (No. 1) is characterized by the absence of foraminifers. The pebbly sand (Unit 1) in Zone 1 is interpreted as a glacial deposit. Cassidulina reniforme is the most abundant benthonic foraminiferal species in Zone 2 and is suggestive of bottom-water temperatures between -1 and 2°C and salinities ranging from 28 to 33‰. The most abundant species in Zone 3 are Islandiella norcrossi and Cassidulina reniforme. The increase in abundance of Islandiella norcrossi and corresponding decrease in abundance of Cassidulina reniforme from Zone 2 to Zone 3 is related to changing bottom-water conditions. The increase in the abundance of _Islandiella_ _norcrossi_ in Zone 2 may be related to increased bottom-water temperatures ($>2^{o}C$) and/or increased salinities (> 33‰). Bottom-water temperatures between 0 and $4^{o}C$ and salinities greater than 34‰ are proposed for Zones 4 and 5 which contain large numbers of _Elphidium_ _excavatum_ forma _clavata_, _Nonionellina_ _labradorica_, _Buccella_ _frigida_ and _Islandiella_ _helenae_.

The planktonic foraminifer, _Neogloboquadrina_ _pachyderma_, is present in all samples from Site 31 (Fig. 11) and in samples from the lower part of the marine portion of the cored section from Site 32 (Fig. 12). Sinistrally coiled (>95%) planktonic tests suggest that surface waters were not permanently ice-covered and surface-water temperatures were between 0 and $4^{o}C$ during deposition of the sediments at Site 31 and deposition of the sediments in the lower part of the section at Site 32.

Two radiocarbon dates were obtained on invertebrate fossils from Site 31 (Fig. 11). The date of 9170 ± 130 years BP (TO-771) from the lower part of the section is older than any previously reported date from east-central Ellesmere Island and suggests that Site 31 was deglaciated before _circa_ 9200 radiocarbon years BP. The date of 3310 ± 70 years BP (TO-567) from the middle part of the section provides a maximum age for the enclosing sediment.

The radiocarbon date of 7590 ± 120 (TO-770) from the lower part of the section at Site 32 (Fig. 12) is similar to the oldest dates on marine shells from Inglefield Land.

The date indicates that Site 32 was deglaciated before <u>circa</u> 7600 radiocarbon years BP.

Gypsum crystal are present in the upper part of the cored section from Site 32. The presence of gypsum in the samples is best explained by the process outlined by Schnitker <u>et</u> <u>al</u>. (1980). Oxidation of sulphides (<u>e</u>.<u>g</u>., FeS_2) in the sediment during exposure to the atmosphere released dissolved sulphate which lowered the pH of the interstitial water. Calcareous tests dissolved in the acid interstitial water. Desiccation of the sediment during storage resulted in an increase in calcium and sulphate in the interstitial water and precipitation of gypsum.

A comparison of the number of foraminiferal tests $\geq$75 µm and $\geq$150 µm in the samples from Site 31 indicates that large numbers of tests are lost by using the coarser sieve. Furthermore, benthonic foraminiferal assemblages based on residues $\geq$150 µm are characterized by the larger but, not necessarily the most abundant species. The use of different sieve sizes results in benthonic foraminiferal assemblages characterized by different abundant species. The paleoenvironmental interpretation of the fossil assemblages based on the abundant benthonic foraminiferal species may differ depending on the sieve size used.

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APPENDIX I

List of foraminifers identified to specific level

[1]Adercotryma glomerata (Brady) = Adercotryma glomeratum (Brady): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 26, Pl. 8, fig. 1-4.

Astacolus hyalacrulus Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 52, Pl. 9. fig. 1-4.

Astrononion gallowayi Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 90, Pl. 17, fig. 4-7.

Bolivina pseudopunctata Höglund: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 111, Pl. 20, fig. 13-14.

Buccella arctica Voloshinova = Buccella hannai (Phleger and Parker) arctica Voloshinova: Rodrigues and Hooper, 1982, Jour. Foram. Res., v. 12, no. 4, p. 343, Pl. 1, fig. 2-3, 5, 6, 10.

Buccella calida (Cushman and Cole): Rodrigues and Richard, 1986, Geol. Surv. Can., Paper 85-22, p. 20, Pl. 1, fig. 15.

Buccella frigida (Cushman): Schafer and Cole, 1978, Geol. Surv. Can., Paper 77-30, p. 27, Pl. 8, fig. 1a-1b.

Buccella tenerrima (Bandy): Rodrigues and Hooper, 1982, Jour. Foram. Res., v. 12, no. 4, p. 343, Pl. 1, fig. 1, 4, 7.

Bulimina aculeata d'Orbigny: Rodrigues and Hooper, 1982, Jour. Foram. Res., v. 12, no. 4, p. 343, Pl. 2, fig. 2-4, 6-8, 10-12.

Buliminella hensoni Lagoe = Buliminella elegantissima (d'Orbigny) var. hensoni Lagoe, 1977, Jour. Foram. Res., v. 77, no. 2, p. 125, Pl. 3, fig. 20-22; text-fig. 6c, 6f.

Cassidulina reniforme Nørvang: Rodrigues et al., 1980, Jour. Foram. Res., v. 10, no. 1, p. 58, Pl. 2, fig. 2, 4, 6; Pl. 3, fig. 3, 6, 9, 11, 12; Pl. 5, fig. 10-12.

Cassidulina teretis Tappan: Rodrigues et al., 1980, Jour. Foram. Res., v. 10, no. 1, p. 59, Pl. 2, fig. 1, 3, 5; Pl. 5, fig. 1, 4, 7; Pl. 6, fig. 7, 10.

Cibicides lobatulus (Walker and Jacob): Vilks et al., 1982, Geol. Soc. Amer. Bull., Pl. 1, fig. 20a-20c.

[1] Cribrostomoides crassimargo (Norman) = Alveolophragmium crassimargo (Norman): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 29, Pl. 3, fig. 1-3.

[1] Cribrostomoides jeffreysi (Williamson) = Alveolophragmium jeffreysi (Williamson): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 31, Pl. 3, fig. 4-7.

Dentalina frobisherensis Loeblich and Tappan, 1953, Smithson. Misc. Coll., v.121, no. 7, p. 55, Pl. 10, fig. 1-9.

Elphidiella arctica (Parker and Jones): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 106, Pl. 20, fig. 1-3.

Elphidium bartletti Cushman: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 96, Pl. 18, fig. 10-14.

Elphidium excavatum (Terquem) forma clavata Cushman: Miller et al., 1982, Jour. Foram. Res., v. 12, no. 2, p. 125, Pl. 1, fig. 5-8; Pl. 2, fig. 3-8; Pl. 3, fig. 3-8; Pl. 4, fig. 1-6; Pl. 5, fig. 4-8; Pl. 6, fig. 1-5.

Elphidium subarcticum Cushman: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 105, Pl. 19, fig. 5-7.

Eoeponidella pulchella (Parker): Rodrigues and Richard, 1986, Geol. Surv. Can., Paper 85-22, p. 20, Pl. 1, fig. 4.

Epistominella arctica Green, 1960, Micropaleontology, v. 6, no. 1, p. 71, Pl. 1, fig. 4a-4b.

Fissurina cucurbitasema Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 76, Pl. 14, fig. 10-11.

Fissurina marginata (Montagu): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 77, Pl. 14, fig. 6-9.

Fissurina reniformis (Sidebottom): Rodrigues and Richard, 1986, Geol. Surv. Can., Paper 85-22, p. 20, Pl. 1, fig. 9.

Fissurina ventricosa (Wiesner): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 79, Pl. 14, fig. 15.

Fursenkoina loeblichi (Feyling-Hanssen): Rodrigues and Hooper, 1982, Jour. Foram. Res., v. 12, no. 4, p. 344, Pl. 1, fig. 12-15.

Glandulina laevigata d'Orbigny: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 81, Pl. 16, fig. 2-5.

Glandulinoides ittai (Loeblich and Tappan) = *Dentalina ittai* Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 56, Pl. 10, fig. 10-12.

Haynesina orbicularis (Brady) = *Elphidium orbiculare* (Brady): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 102, Pl. 19, fig. 1-4.

Islandiella helenae Feyling-Hanssen and Buzas: Rodrigues *et al.*, 1980, Jour. Foram. Res., v. 10, no. 1, p. 49, Pl. 1, fig. 1, 3, 5; Pl. 4, fig. 3, 6, 9; Pl. 6, fig. 1-2.

Islandiella islandica (Nørvang): Rodrigues *et al.*, 1980, Jour. Foram. Res., v. 10, no. 1, p. 49, Pl. 1, fig. 2, 4, 6; Pl. 3, fig. 2, 5, 8.

Islandiella norcrossi (Cushman): Rodrigues *et al.*, 1980, Jour. Foram. Res., v. 10, no. 1, p. 49, Pl. 4, fig. 1, 4, 7, 10; Pl. 6, fig. 8-9.

Lagena gracillima (Seguenza): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 60, Pl. 11, fig. 1-4.

Lagena laevis (Montagu): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 61, Pl. 11, fig. 5-8.

Lagena meridionalis Wiesner: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 62, Pl. 12, fig. 1.

Lagena mollis Cushman: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 63, Pl. 11, fig. 25-27.

Melonis zaandami (van Voorthuysen) = *Nonion zaandamae* (van Voorthuysen): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 87, Pl. 16, fig. 11-12.

[2]*Neogloboquadrina pachyderma* (Ehrenberg) = *Globorotalia pachyderma* (Ehrenberg): Vilks, 1975, Jour. Foram. Res., v. 5, no. 4, Pl. 1, fig. 1a-1b, 2a-2b, 3a-3b; Pl. 2, fig. 1a-1b, 2a-2b, 3a-3b; Pl. 3, fig. 1a-1b, 2a-2b, 3a-3b.

Nonionellina labradorica (Dawson) = *Nonion labradoricum* (Dawson): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 86, Pl. 17, fig. 1-2.

Oolina acuticostata (Reuss) = *Lagena apiopleura* Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, P. 59, Pl. 10, fig. 14-15.

Oolina _caudigera_ (Wiesner): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 67, Pl. 13, fig. 1-3.

Oolina _hexagona_ (Williamson): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 69, Pl. 14, fig. 1-2.

Oolina _lineata_ (Williamson): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 70, Pl. 13, fig. 11-13.

Oolina _melo_ d'Orbigny: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 71, Pl. 12, fig. 8-15.

Oolina _striatopunctata_ (Parker and Jones): Loeblich and Tappan, 1953, Smithson. Misc. Col., v. 121, no. 7, Pl. 12, fig. 2-5.

Oolina _williamsoni_ (Alcock): Rodrigues and Richard, 1986, Geol. Surv. Can., Paper 85-22, p. 21, Pl. 1, fig. 8.

Parafissurina _fovigera_ (Buchner) = _Lagena_ _fovigera_ Buchner, 1940, Nova Acta Leopoldina, Neue Folge, v. 9, no. 62, p. 541, Pl. 29, fig. 627-629.

Patellina _corrugata_ Williamson: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 114, Pl. 21, fig. 4-5.

Pateoris _hauerinoides_ (Rhumbler): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 42, Pl. 6, fig. 8-12; text-fig. 1a-1b.

Pseudoparrella _takayanagii_ (Iwasa) = _Epistominella_ _takayanagii_ Iwasa, 1955, Jour. Geol. Soc. Japan, v. 61, p. 16, text-fig. 4.

Pyrgo _williamsoni_ (Sylvestri): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 48, Pl. 6, fig. 1-4.

Quinqueloculina _agglutinata_ Cushman: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 39, Pl. 5, fig. 1-4.

Quinqueloculina _arctica_ Cushman: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 40, Pl. 5, fig. 11-12.

Quinqueloculina _stalkeri_ Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 40, Pl. 5, fig. 5-9.

<u>Robertinoides suecicum</u> Höglund, 1947, Zool. Bidrag. Uppsala, v. 26, p. 225, Pl. 18, fig. 4; Pl. 19, fig. 2; text-fig. 200-202, 204.

[1]<u>Spiroplectammina biformis</u> (Parker and Jones): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 34, Pl. 4, fig. 1-6.

<u>Stetsonia horvathi</u> Green, 1960, Micropaleontology, v. 6, no. 1, p. 72, Pl. 1, fig. 6a-6b.

[1]<u>Textularia torquata</u> Parker: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 35, Pl. 2, fig. 19-21.

<u>Trifarina hughesi</u> (Galloway and Wissler): Rodrigues and Hooper, 1982, Jour. Foram. Res., v. 12, no. 4, p. 348, Pl. 2, fig. 1, 5, 9, 13-15.

<u>Triloculina trihedra</u> Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 45, Pl. 4, fig. 10.

[1]<u>Trochammina nana</u> (Brady): Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 50, Pl. 8, fig. 5.

[1]<u>Trochammina quadriloba</u> Höglund: Loeblich and Tappan, 1953, Smithson. Misc. Coll., v. 121, no. 7, p. 51, Pl. 7, fig. 8.

[1]Agglutinated benthonic species

[2]Planktonic species

Others are calcareous benthonic species

APPENDIX II

IsoTrace Laboratory Dating Procedure

The radiocarbon age determinations were carried out by the IsoTrace Laboratory, University of Toronto where measurements are made on the IsoTrace accelerator mass spectrometer. The dates are the average of 2 machine-ready targets measured on different occasions. They have been corrected for natural, preparation and sputtering fractionation to a base of $\delta^{13}C = 0‰$, equivalent to a reservoir correction of 410 years. The dates are quoted in uncalibrated radiocarbon years using the Libby ^{14}C meanlife of 8033 years. The errors represent 68.3% confidence limits.

VITA AUCTORIS

KRIS ALLEN MARENTETTE
Born April 24, 1963 in Windsor, Ontario
Son of Donald and Joyce Marentette

ACADEMIC BACKGROUND

1986 - 1988	University of Windsor, Windsor, Ontario Program: Geology Degree: M. Sc., Geology
1982 - 1986	University of Windsor, Windsor, Ontario Program: Geology Degree: B. Sc., Honours Geology
1977 - 1982	J. L. Forster Collegiate Institute, Windsor, Ontario Grade XIII Honours Graduate

EMPLOYMENT HISTORY

1986 - 1988	Graduate Teaching Assistant
Summer 1986 - 1987	Geological Survey of Canada, Ottawa, Ontario Field and Research Assistant, Ellesmere Island, Arctic Canada
Summer 1984 - 1985	University of Windsor, Windsor, Ontario Field and Research Assistant

SCHOLARSHIPS AND ACADEMIC AWARDS

1987 - 1988	Natural Sciences and Engineering Research Council Postgraduate Scholarship (PGS 2) University of Windsor
1986 - 1987	Natural Sciences and Engineering Research Council Postgraduate Scholarship (PGS 1) University of Windsor
1985 - 1986	Stanley E. Slipper Award Canadian Society of Petroleum Geologists Undergraduate Thesis Award University Award University of Windsor

SCHOLARSHIPS AND ACADEMIC AWARDS (continued...)

1984 - 1985	R. K. Jull Memorial Scholarship University of Windsor
	University Award University of Windsor
1983 - 1984	Natural Sciences and Engineering Research Council Undergraduate Summer Research Award University of Windsor
1982 - 1983	Ontario Scholarship
	University Entrance Award Elizabeth Ellen Tillston Memorial Fund University of Windsor

ACHIEVEMENT

Selected to represent the University of Windsor at the Student Industry Field Trip in Calgary, Alberta (May 1985, 2 weeks)